SCHOOL OF CIVIL ENGINEERING

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Informational Report

JHRP-88/19

USER GUIDE FOR PC STABL 5M

Eftychios Achilleos

PURDUE UNIVERSITY

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USER GUIDE FOR
PC STABL 5M

TO: H. L. Michael, Director — Dec 15, 1988
Joint Highway Research Project

FROM: C. W. Lovell, Research Engineer — File 6-14-12
Joint Highway Research Project

The attached report summarizes instructions to STABL users for all 2-D versions of STABL, up to and including STABL5M. It essentially replaces all previous User Guides, and is expected to have a wide distribution.

Respectfully submitted

C. W. Lovell
Research Engineer

USER GUIDE FOR PC STABL 5M

by

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December 15, 1988

ABSTRACT

This report describes the operation of the two-dimensional, limit equilibrium slope stability program PCSTABL5M, developed to handle general slope stability problems by the simplified Jambu, simplified Bishop, and Spencer method of slices. The contents of this report summarize previous research conducted in Purdue University under the guidance of Prof. C. W. Lovell.

A short introduction of the capabilities of the program is presented, followed by a more analytical description. Detailed explanation of the input commands, with an explanation of the usual type of errors experienced by first users is also given. The manual includes two appendices. Appendix A deals with an example problem which is solved using all available methods, and generators. Appendix B gives miscellaneous information about STABL.

TABLE OF CONTENTS

(Table of contents continued)

(Table of contents continued)

LIST OF FIGURES.

(list of figures continued)

(list of figures continued)

INTRODUCTION

STABL is a computer program written in FORTRAN IV source language for the general solution of slope stability problems by a two-dimensional limiting equilibrium method. It is written for the Microsoft Fortran compiler package. The calculation of the factor of safety against instability of a slope is performed by the method of slices. The particular methods employed in this version of STABL (PCSTABL5M) are the simplified Bishop method, applicable to circular shaped failure surfaces. the simplified Janbu method, applicable to failure surfaces of general shape, and the Spencer method, applicable to any type of surface. The simplified Janbu method has an option to use a correction factor, developed by Janbu, which can be applied to the factor of safety to reduce the conservatism produced by the assumption of no interslice forces.

STABL features unique random techniques for generation of potential failure surfaces for subsequent determination of the more critical surfaces and their corresponding factors of safety. One technique generates circular; another, surfaces of sliding block character; and a third, more general irregular surfaces of random shape. The means for defining a specific trial failure surface and analyzing it is also provided.

Complications which STABL is programmed to handle include the following: heterogeneous soil systems, anisotropic soil strength properties, excess pore water pressure due to shear, static groundwater and surface water, pseudo-static earthquake loading, surcharge boundary loading, and tieback loading.

The tieback loading feature provides for the input of horizontal or near horizontal tieback or line loads for analyzing the overall stability of tied-back or braced slopes and retaining walls. The STABL program is the only known computer program with the ability to analyze slopes subjected to tieback or concentrated loads using the simplified Janbu, simplified Bishop, and Spencer method of slices.

Plotted output is provided as a visual aid to confirm the correctness of problem input data . STABL-generated error messages pinpoint locations where input data are inconsistent with the STABL input requirements. The STABL free-form data input eases the task of preparing data, resulting in a reduction of input errors.

This manual is not intended to totally explain how STABL functions or what assumptions are made to arrive at a solution. However, it has sometimes been found useful to do so when explanations of the use of certain features of STABL are presented. For a more detailed explanation of the logical operation of STABL and mathematical models employed refer to the JHRP Reports: "Computer Analysis of General Slope Stability Problems", JHRP-75-8, June 1975, "Computerized Slope Stability Analysis for Indiana Highways", JHRP-77-25, December 1977; "Slope Stability Analysis Considering Tiebacks & other Concentrated Loads",JHRP-86-21; and "STABL5... The Spencer Method Of Slices, Final Report". JHRP-85-17.

PROBLEM GEOMETRY

To begin, it is necessary to plot the problem geometry to scale on a rectangular coordinate grid. Coordinate axes should be chosen carefully such that the total problem is defined within the first quadrant. This enables the graphical aspects of the program to function properly. In doing this, potential failure surfaces which may develop beyond the toe or the crest of the slope should be anticipated (Figure 1). Deep trial failure surfaces passing below the horizontal axis are not allowed , as well as, trial failure surfaces which extend beyond the defined ground surface in either direction. If any coordinate point defining the problem geometry is detected by the program to lie outside the first quadrant, an appropriate error code is displayed and execution of STABL is later terminated.

Graphic output resulting from execution of STABL is scaled to a 5 in. x 8 in. plot of the problem geometry. The origin of the coordinate system referencing the problem geometry is retained as the origin of the plot, and the scale is maximized so that the extreme geometry point or points lie just within the boundaries of the 5 in. x 8 in. plot. Therefore, it is advantageous to fit the problem geometry to the coordinate axes with this in mind. Situations where the resulting plotted profile would be too small in scale to be useful for interpretation should be avoided (Figure 2). Fiqure 1 is an excellent example of well chosen coordinates, where there is enough room for possible failure surface development, and the profile geometry is plotted to the largest scale possible within the allowed format. If these requirements are not considered before the input data are prepared, revision of the entire set of data could later become a necessity.

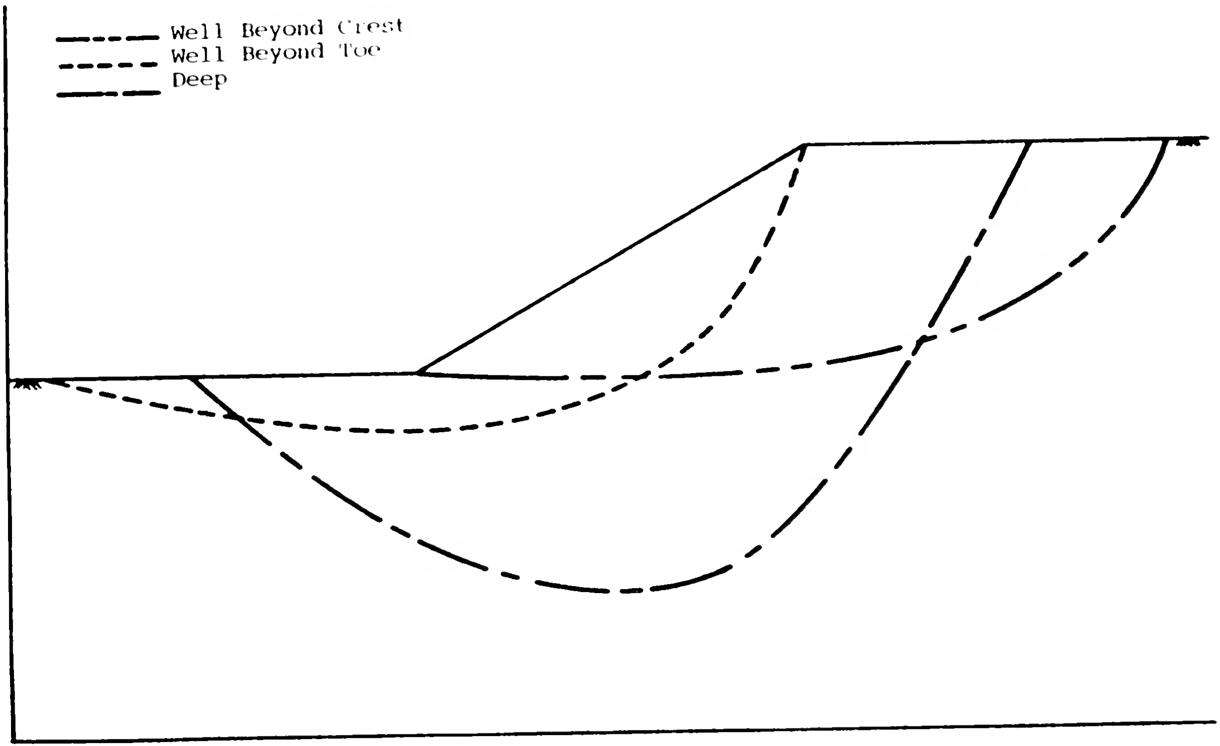
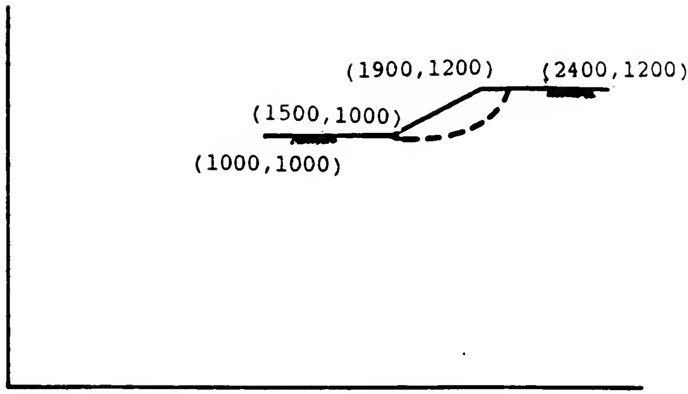
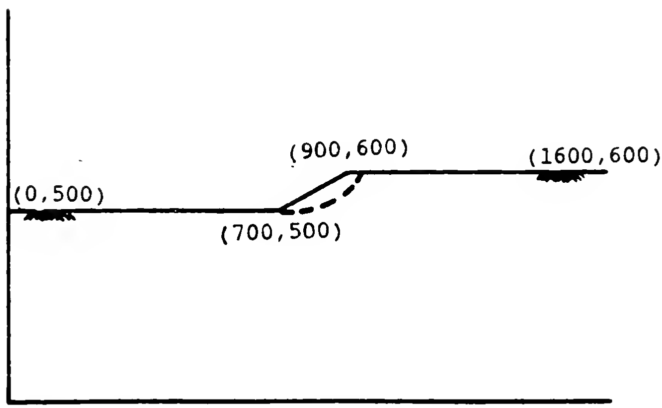


Figure 1: Extent of potential failure surfaces.



Coordinates Too Large in Comparison with Height and Length of Slope



Too Much Room Allowed Beyond the Toe and Crest of Slope in Comparison to its Height and Length

Figure 2: Scaling resulting from correct but inadequate definition of problem.

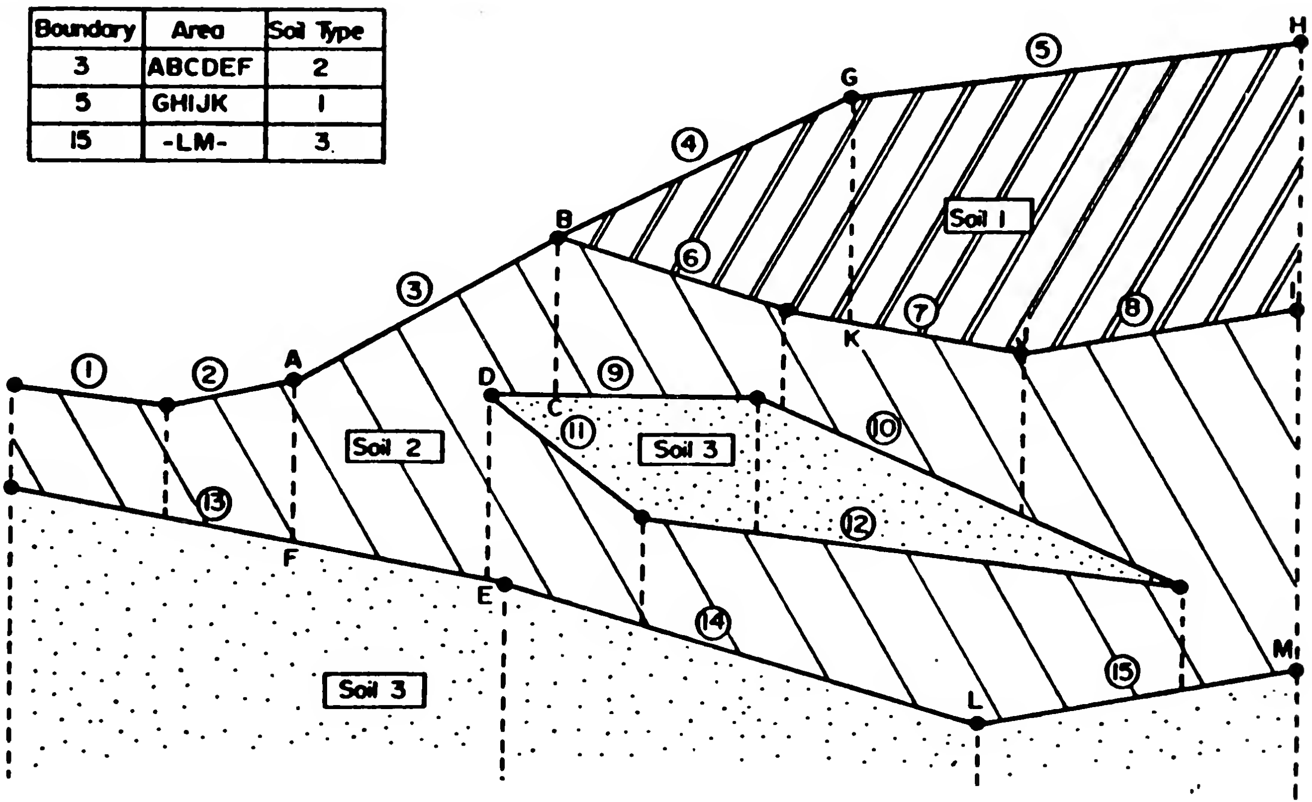
Profile Boundaries

The ground surface and subsurface demarcations between regions of differing soil parameters are approximated by straight line segments. Any configuration can be portrayed so long as the sloping ground surface faces the vertical axis and does not contain an overhang. Vertical boundaries should be specified slightly inclined to the right for computational reasons (e.g., Xleft = 100.0, Xright = 100.1).

Assigned with each surface and subsurface boundary is a soil type which represents a set of soil parameters describing the area projected beneath. Vertical lines, passing through the end points of each boundary, bound the area in lateral extent. The area below a boundary may or may not be bound at its bottom by another boundary beneath which different soil parameters would be defined (Figure 3).

The program requires an order by which boundary data are prepared. The boundaries may be assigned temporary index numbers for ordering by the following procedure. The ground surface boundaries are numbered first, from left to right consecutively, starting with (1). All subsurface boundaries are then numbered in any manner as long as no boundary lies below another having a higher number. That is, at any position which a vertical line might be drawn, the temporary index numbers of all boundaries intersecting that line must increase in numerical order from the ground surface downward. After all the boundaries have been temporarily indexed, the data for each boundary should be prepared in that order.

The data set describing a profile boundary line segment consists of X and Y coordinates of the left and right end points, and a soil type number indicating the soil type beneath. The end points of each boundary are specified with the left point proceeding the right, and with the X coordinate of each point required to precede its complimentary Y coordinate.



Boundary	Area	Soil Type
3	ABCDEF	2
5	GHIJK	1
15	-LM-	3

Figure 3: Relationship of soil to boundaries.

Piezometric Surfaces

If the problem contains one or more piezometric surfaces which would intersect a potential failure surface, they can be approximated by a series of coordinate points connected by straight line segments. If used, the piezometric surfaces must be defined continuously across the horizontal extent of the region to be investigated for possible failure surfaces. It is wise to extend the piezometric surfaces as far in each lateral direction as the ground surface is defined, to insure meeting this last requirement (Figure 4). Data for the coordinate points must be ordered progressing from left to right. Each point on a piezometric surface is defined by a X and Y coordinate specified in that order.

The connecting line segments defining a piezometric surface may lie above the ground surface and also may lie coincident with the ground surface or any profile boundary. This enables expression of not only the ground water table but also surfaces of seepage and still water surfaces of bodies of water such as lakes and streams. The option of defining several piezometric surfaces makes it possible to model conditions of artesian or perched water tables.

In early versions of STABL the pore pressure was calculated using a method referred in this manual as the "old method". When a phreatic surface is specified the "old method" computes pore pressure based on hydrostatic pressure, i.e., the head is the vertical distance from the base of the slice to the phreatic surface immediately above (see Figure 5) (Siegel, 1975a; Siegel, 1975b; Boutrup, 1977). This is a conservative estimate, increasing more in conservatism with a steeper sloping piezometric surface. This pressure head can be as much as 30% higher than the actual head when the piezometric surface is dipping at 35 deg(see Figure 6).

To overcome this conservatism a new method was proposed referred as the "perpendicular method". The perpendicular method approximates the equipotential line as a straight line from the base of the slice perpendicular to the line through the piezometric surface bounding the top of that slice (see Figure 5).

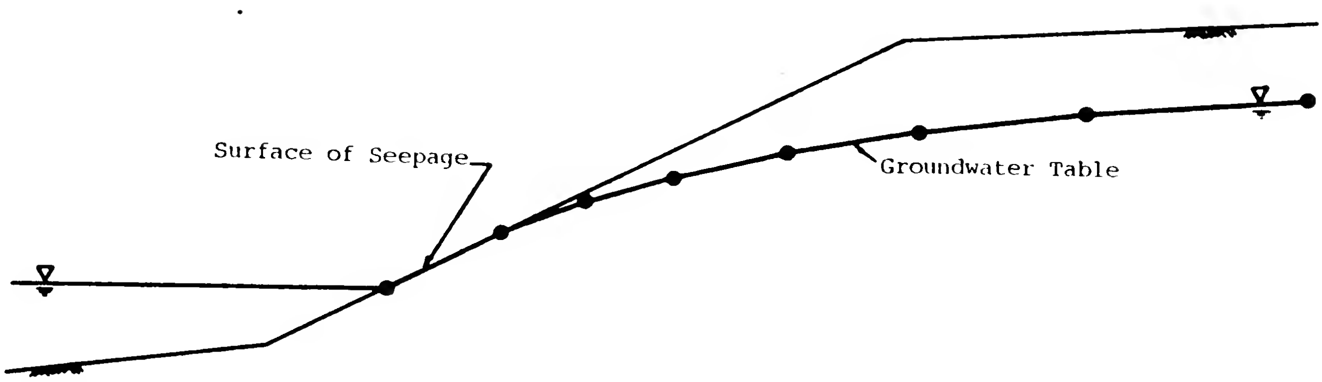


Figure 4: Water surface defined across entire extent of defined problem.

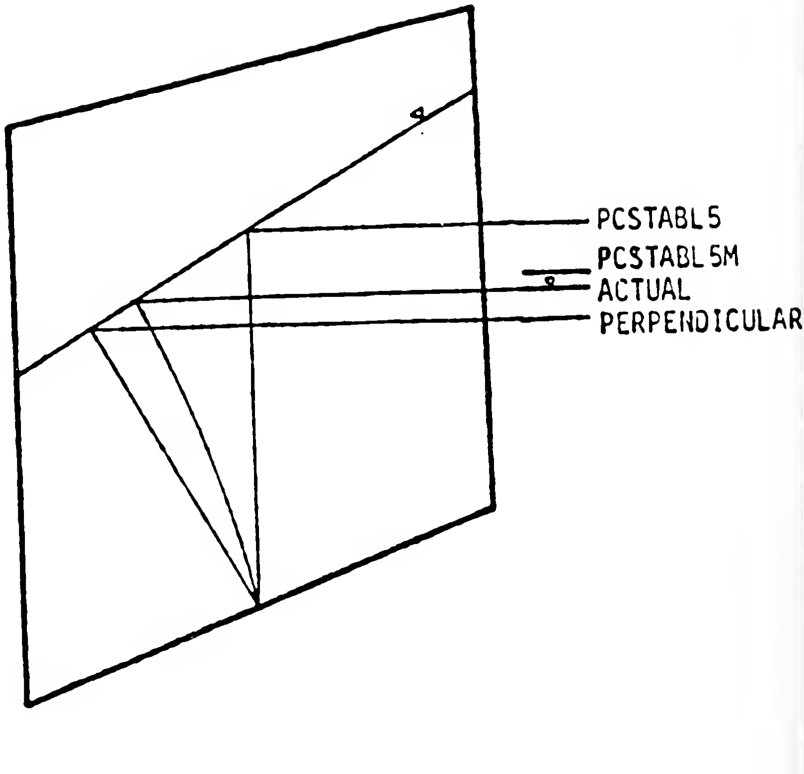
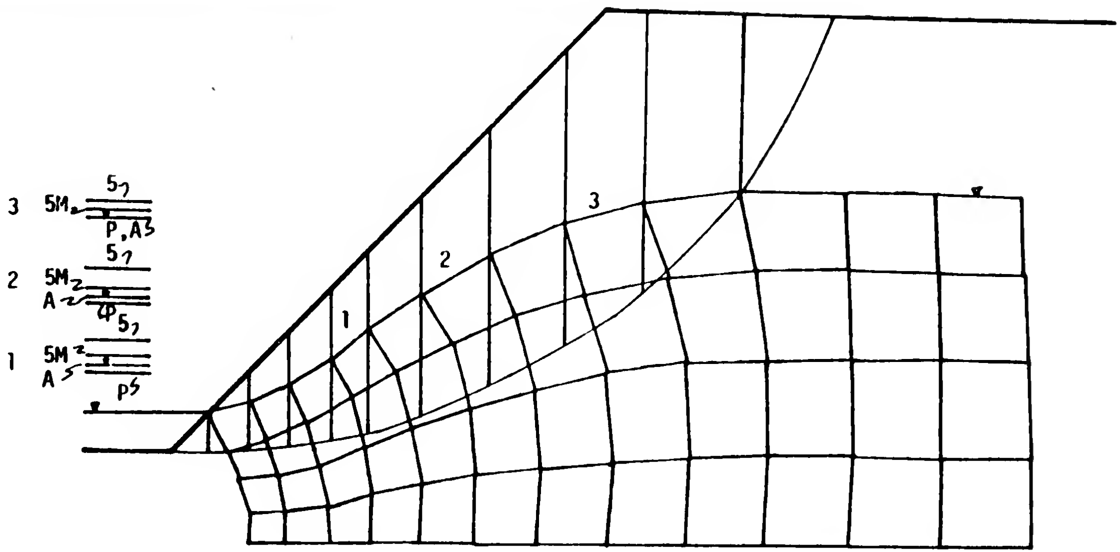


Figure 5: Methods of Pore Pressure Determination.



1 - 35° dipping piezometric surface
2 - 29° dipping piezometric surface
3 - 17° dipping piezometric surface

5 - PCSTABL5 method of pore pressure determination
5M - PCSTABL5M method of pore pressure determination
P - Perpendicular method of pore pressure determination
A - Actual pore pressure

Figure 6: Hand/Plot of Flow/Net/Slope.

However, this tends to produce nonconservative pore pressures, increasing more in nonconservatism with a steeper sloping piezometric surface. The pressure head can be as much as 10% lower than the actual head when the piezometric surface is dipping at 35 deg. (see Figure 6).

Since the old method is increasing in conservatism with steeper phreatic surface and the perpendicular method is increasing in nonconservatism, the average value of the two would tend to control the degree of conservatism. The average value is conservative since the old method is much more conservative than the perpendicular method is nonconservative. The pressure head is about 9% higher than the actual head when the piezometric surface is dipping at 35 deg (see Figure 6).

SOIL PARAMETERS

Each soil type is described by the following set of isotropic parameters: the moist unit weight, the saturated unit weight, the Mohr-Coulomb strength intercept, the Mohr-Coulomb strength angle, a pore pressure parameter, a pore pressure constant, and an integer representing the number of the piezometric surface that applies to this soil.

The moist unit weight and the saturated unit weight are total unit weights, and both are specified to enable STABL to handle zones divided by a water surface. In the case of a soil zone totally above the water surface, the saturated unit weight will not be used, however, some value must be used for input regardless. Any value including zero will do. Similarly for the case where a soil zone is totally submerged, the moist unit weight will not be used. Again, some value must be used for input.

Either an effective stress analysis (ϕ', c$'$) or total stress analysis (c, ϕ=0) may be performed by using the appropriate values for the Mohr-Coulomb strength parameters.

Excess pore water pressure due to shear can be assumed to be related to the overburden by the single parameter r_u. The overburden does not include surcharge boundary loads. The pore pressure constant u_c of a soil type defines a constant pore pressure for any point within the soil described. Either or both of these two options for specifying pore pressures may be used, in combination with pore pressure related to a specified piezometric surface,to describe the pore pressure regime.

Anisotropic Soil

Soil types exhibiting anisotropic strength properties are described by assigning Mohr-Coulomb strength parameters to discrete ranges of direction. The strength parameters would vary from one discrete direction range to another.

The orientation of all line segments defining any potential failure surface can be referenced with respect to their inclination entirely within a range of direction between -90 deg and +90 deg with respect to the horizontal. Therefore, the selection of discrete ranges of direction is confined to these limits. The entire range of potential orientation must be assigned strength values.

Each direction range of an anisotropic soil type is established by specifying the maximum (counterclockwise) inclination α_i of the range (Figure 7). The data consist of this inclination limit and the Mohr-Coulomb strength angle and strength intercept for each discrete range. Data for each discrete range are required to be prepared progressing in counterclockwise order, starting with a first range from -90 deg to α_1 (specifying α_1 as counterclockwise direction limit). The process is repeated for each soil type with anisotropic strength behavior.

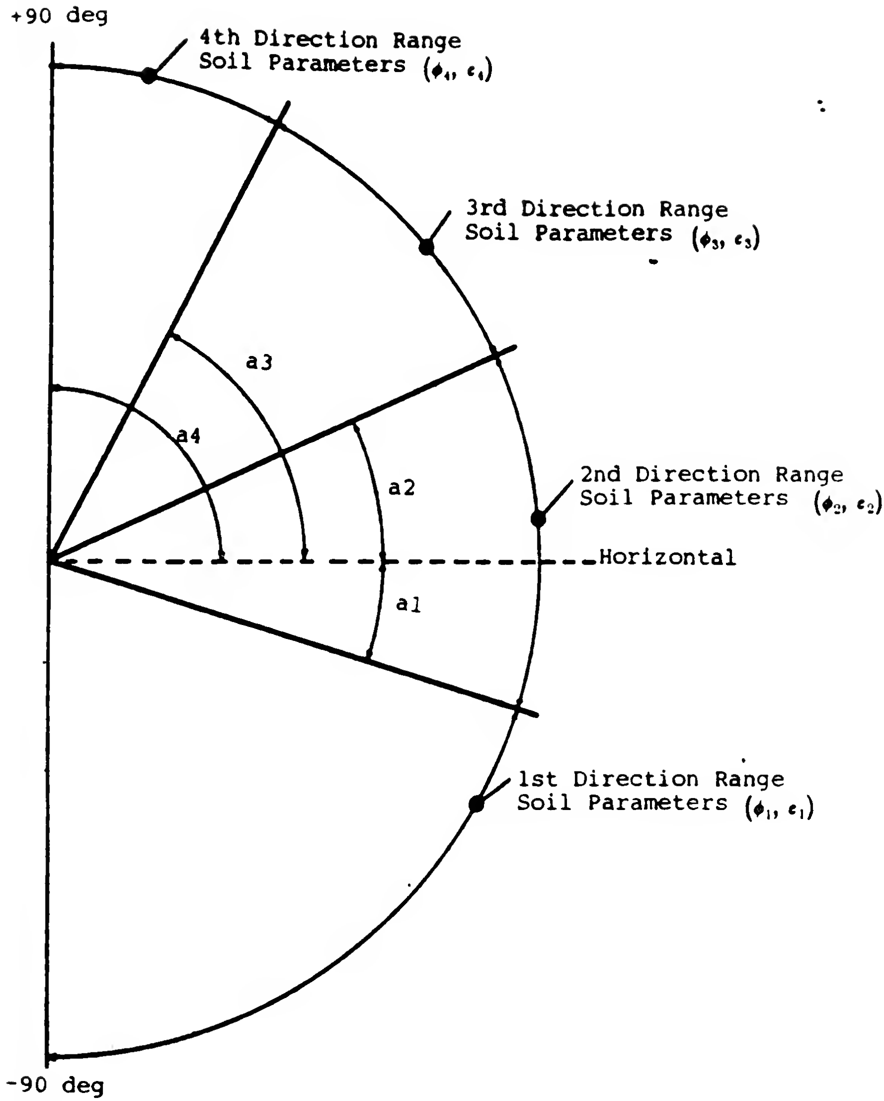


Figure 7: Strength assignment to four discrete direction ranges

BOUNDARY LOADS

Uniformly distributed boundary loads applied to the ground surface are specified by defining their extent, intensity, and direction of application (Figure 8). The limiting equilibrium model used for analysis treats the boundary loads as strip loads of infinite length. The major axis of each strip load is normal to the two-dimensional X-Y plane within which the geometry of slope stability problems is solved. Therefore, the extent of a boundary load is its width in the two-dimensional plane.

Data for each boundary load consist of the left and right X coordinates which define the horizontal extent of load application, the intensity of the loading, and its inclination. The intensity specified should be in terms of the load acting on a horizontal projection of the ground surface rather than the true length of the ground surface. Inclination is specified positive counterclockwise from the vertical. The boundaries must be ordered from left to right and are not allowed to overlap.

A boundary load whose intensity varies with position can be approximated by substituting a group of statically equivalent uniformly distributed loads which abut one another. The sum of the widths of the substitute loads should equal the width of the load being approximated. The inclinations should be equivalent, and the intensities of substitute loads should vary, as does the load being approximated.

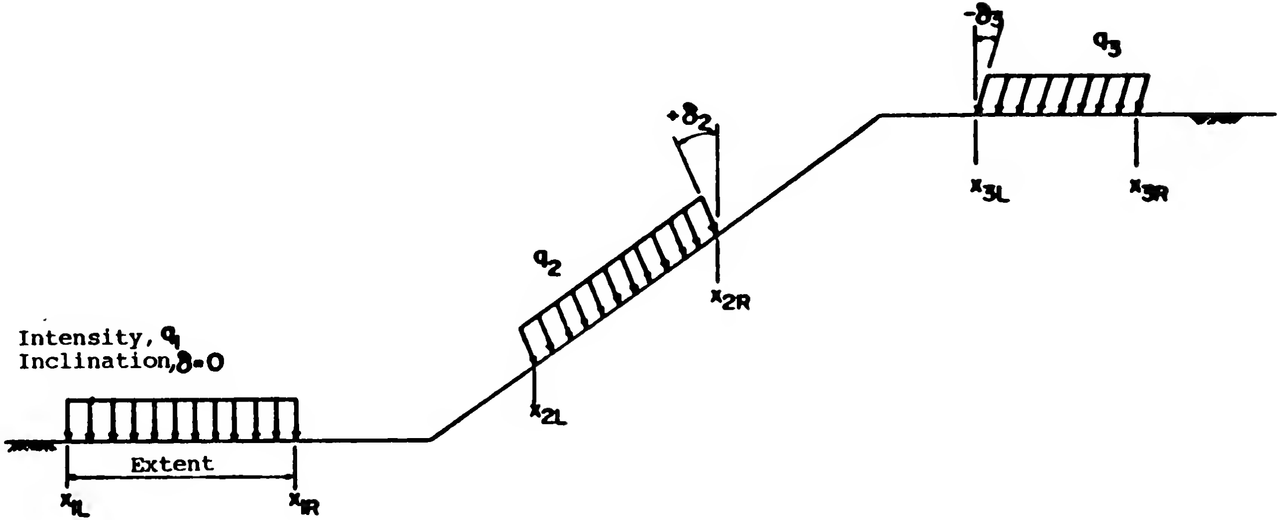


Figure 8: Definition of surcharge boundary loads.

EARTHQUAKE LOADING

The use of earthquake coefficients allows for a pseudo-static representation of earthquake effects within the limiting equilibrium model. A direct relationship is assumed to exist between the pseudo-static earthquake force acting on the sliding mass and the weight of the sliding mass. Specified horizontal and vertical coefficients are used to scale the horizontal and vertical components of the earthquake force relative to the weight of the sliding mass. Positive horizontal and vertical earthquake coefficients indicate that the horizontal and vertical components of the earthquake force are directed leftward and upward, respectively. Negative coefficients are allowed.

The inertial forces due to the seismic coefficients are at the center of gravity of each slice. These forces do not change the pre-earthquake static pore pressures in the slope. If significant excess pore pressures changes or loss of shear strength is expected, or in the case of a "high risk" slope, a complete dynamic analysis should be performed.

Examples of slope stability analysis encountering pseudo-static earthquake loads are described in JHRP-77-25, Section 4.5.4.

CONCEPT OF SEARCHING ROUTINES

STABL can generate any specified number of trial failure surfaces in random fashion. The only limitation is computation time. Usually 100 surfaces are adequate. Each surface must meet specified requirements. As each acceptable surface is generated, the corresponding factor of safety is calculated. The ten most critical are accumulated and sorted by the values of their factors of safety. After all the specified number of surfaces are successfully generated and analyzed, the ten most critical surfaces are plotted so the pattern may be studied.

If the pattern is compact such that the ten most critical surfaces form a thin zone, and if the range in the value of the factor of safety for these ten surfaces is small, an additional refined search would be unnecessary. However, if just the opposite is true, an additional search with stricter surface requirements would then be necessary. There are two exceptions to this last case. The first is when one, some, or all of the ten most critical surfaces have a factor of safety below a value of 1, or perhaps a minimum value the user has established. The second is when the most critical surface has a very large value for the factor of safety, much greater than the criterion for acceptance, and it is obvious that further refinement of a search for a more critical surface will not produce a value of the factor of safety less than the established criterion.

Circular and Irregular Surfaces

The searching routines which generate circular and irregular shaped trial failure surfaces are basically similar in use, and are therefore discussed together.

Trial failure surfaces are generated from the left to the right. Each surface is composed of a series of straight line segments of equal length, except for the last segment which most likely will be shorter. The length used for the line segments is specified.

Generation of an individual trial failure surface begins at an initiation point on the ground surface. The direction, to which the first line segment defining the trial failure surface will extend, is chosen randomly between two direction limits. An angle of 5 deg less than the inclination of the ground surface to the right of the initiation point would be one limit, while an angle of -45 deg to the horizontal would be another limit (Figure 9). The first line segment can fall anywhere between these two limits, but the random technique of choosing its position is biased so that it will lie closer to the -45 deg limit more often than the other.

By specifying zero values for both of the direction limits, the direction limits as described above are automatic. However, the counterclockwise and clockwise direction limits, instead of being calculated under STABL's direction, may be specified. After a preliminary search for the critical surface, it is usually found that all or most of the ten most critical surfaces have about the same angle of inclination for the initial line segments. By restricting the initial line segment within direction limits having a directional range smaller than that which would be used automatically by STABL, and at inclinations which would bracket the initial line segments of surfaces previously determined to be critical, subsequent searches can be conducted more efficiently.

After establishment of the first line segment, a circular shaped trial failure surface is generated by changing the direction of each succeeding line segment by some constant angle (Figure 10) until an intersection of the trial failure surface with the ground surface occurs. In effect, the chords of a circle are generated

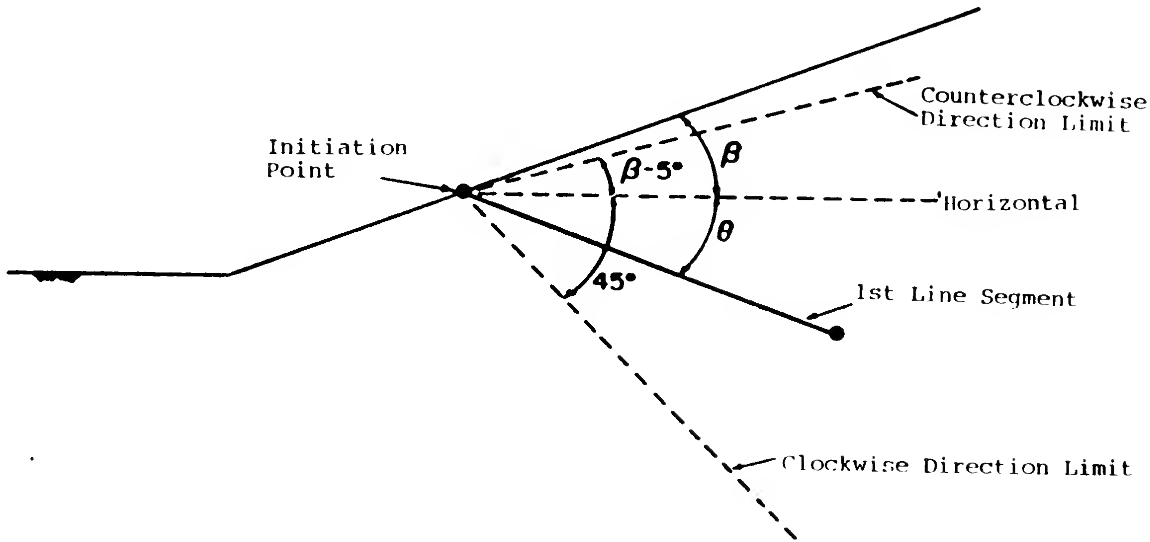


Figure 9: Generation of first line segment.

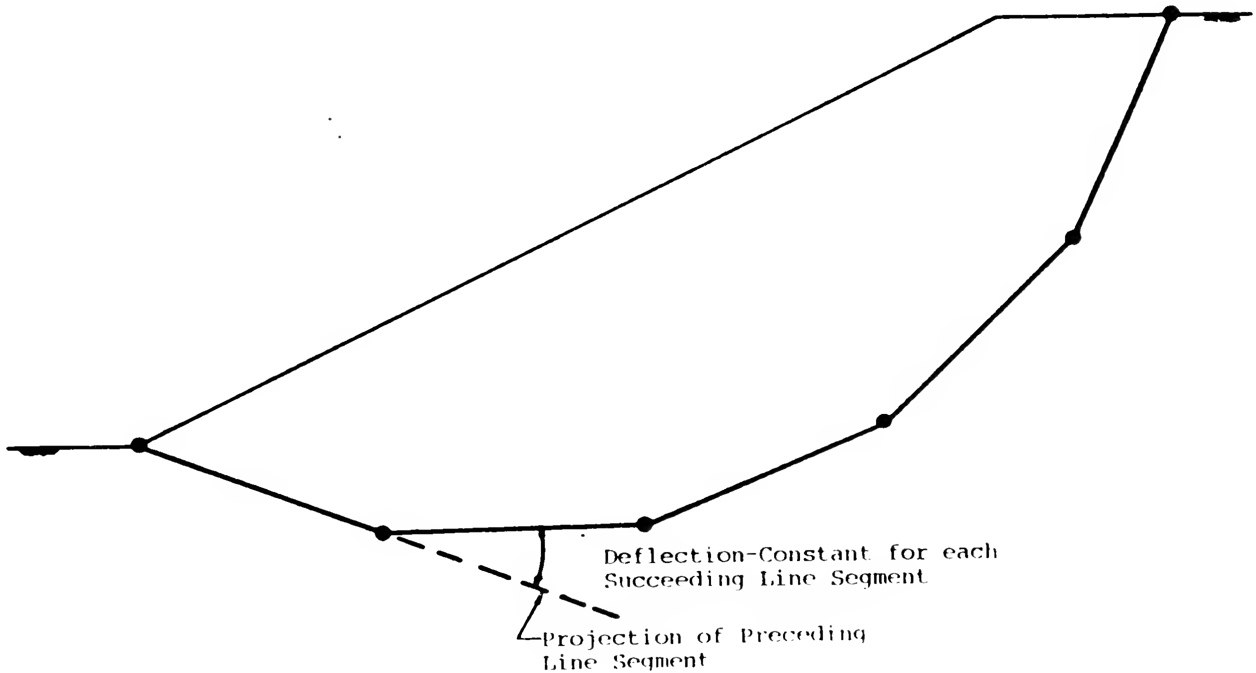


Figure 10: Circular surface generation.

rather than the circle itself. The constant angle of deflection is obtained randomly.

An irregular shaped surface is generated somewhat differently after establishment of the first line segment. The direction of each succeeding line segment is chosen randomly within limits determined by the direction of the preceding line segment. Surfaces with reverse curvature are likely, and if a very short length is used for the line segments, a significant amount of kinkiness in the surfaces will be inevitable. Some reverse curvature is desirable but extreme kinkiness is not. To avoid the second case the length of the line segment selected should in general not be shorter than 1/4 to 1/3 the height of the slope.

When using either of these generation techniques to search for a critical failure surface, the following scheme is employed. STABL directs computation of a specified number of initiation points along the ground surface. The initiation points are equally spaced horizontally between two specified points, which are the leftmost and rightmost initiation points. Only the X coordinates of these two points, specified in left-right order, are required. From each initiation point, a specified number of trial failure surfaces are generated. If the left point coincides with the right, a single initiation point results, from which all surfaces are generated. The total number of surfaces generated will equal the product of the number of initiation points and the number of surfaces generated from each.

Termination limits are specified to minimize the chance of proceeding with a calculation of the factor of safety for an unlikely failure surface. If a generated trial failure surface terminates at the ground surface short of the left initiation limit (Figure 11), the surface is rejected prior to calculation of a factor of safety and a replacement is generated. If a generating surface goes beyond the right termination limit, it will be rejected requiring a replacement. The termination limits are also specified in left-right order.

A depth limitation is imposed by specifying an elevation below which no surface is allowed to extend. This is used, for example, to eliminate calculation of the factor of safety for generated surfaces that would extend into a strong horizontal bedrock layer. When a shallow failure surface is expected, the use of

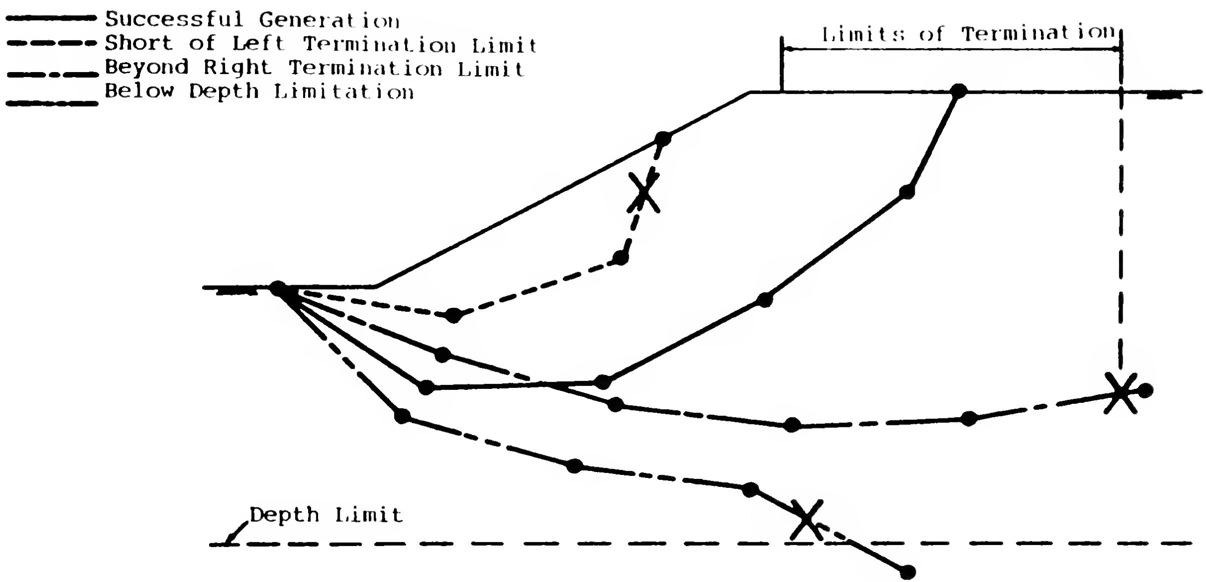


Figure 11: Trial failure surface acceptance criteria.

the depth limitation prevents generation and analysis of deep trial failure surfaces.

An additional type of search limitation may be imposed to handle situations such as variable elevation of bedrock or deliminating a weak zone and confining the search for a critical surface to that area. This type of limitation will be discussed later.

Sliding Block Surfaces

A sliding block trial failure surface generator provides a means through which a concentrated search for the critical failure surface may be performed within a well defined weak zone of a soil profile.

In a simple problem involving a sliding block shaped failure face (Figure 12). the following procedure is used. Two boxes are established within the weak layer with the intent that from within each, a point will be chosen randomly. The two points once chosen define a line segment which is then used as the base of the central block of the sliding mass. Any point within each box has equal likelihood of being chosen. Therefore, a random orientation, position and width of the central block is obtained. The boxes are required to be parallelograms with vertical sides. The top and bottom of a box may have any common inclination. Each box is specified by the length of its vertical sides and two coordinate points which define the intersections of its centerline with its vertical sides (Figure 13).

After the base of the central block is created, the active and passive portions of the trial failure surface are generated using line segments of equal specified length by techniques similar to those used by the circle and irregular trial failure surface generators.

Starting at the left end of the central block base, a line segment of specified length is randomly directed between the limits of 0 deg and 45 deg with respect to the horizontal (Figure 14). The chosen direction is biased towards selection of an angle closer to 45 deg. This process is repeated as necessary until intersection of a line segment with the ground surface occurs, completing the passive portion

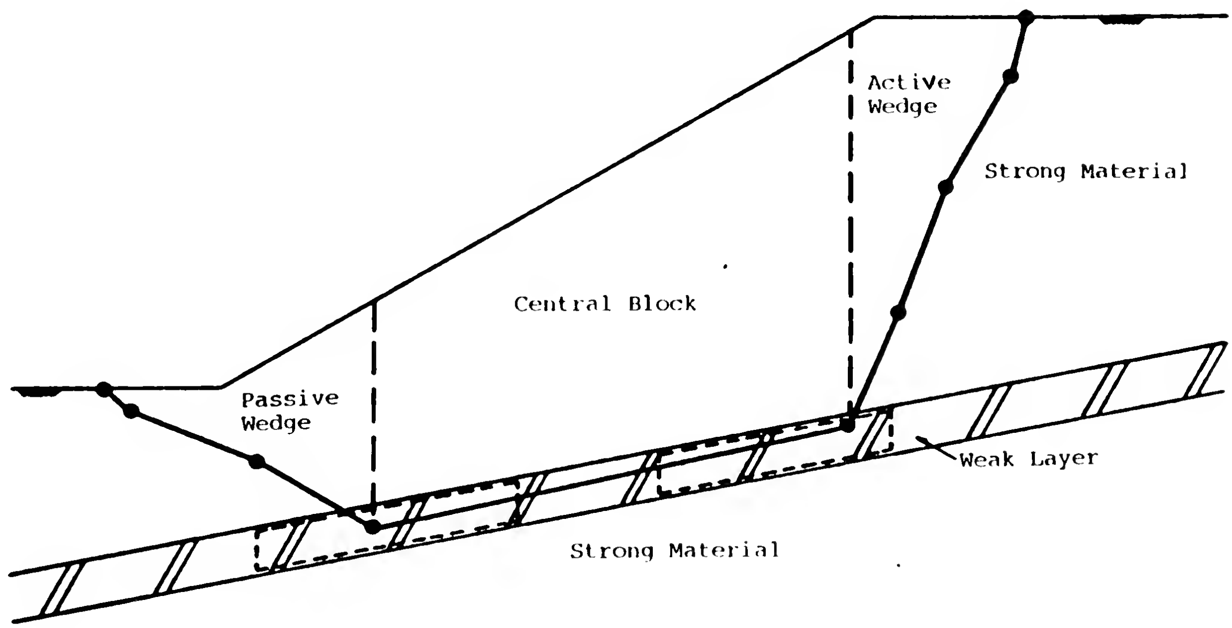


Figure 12: Simple sliding block problem.

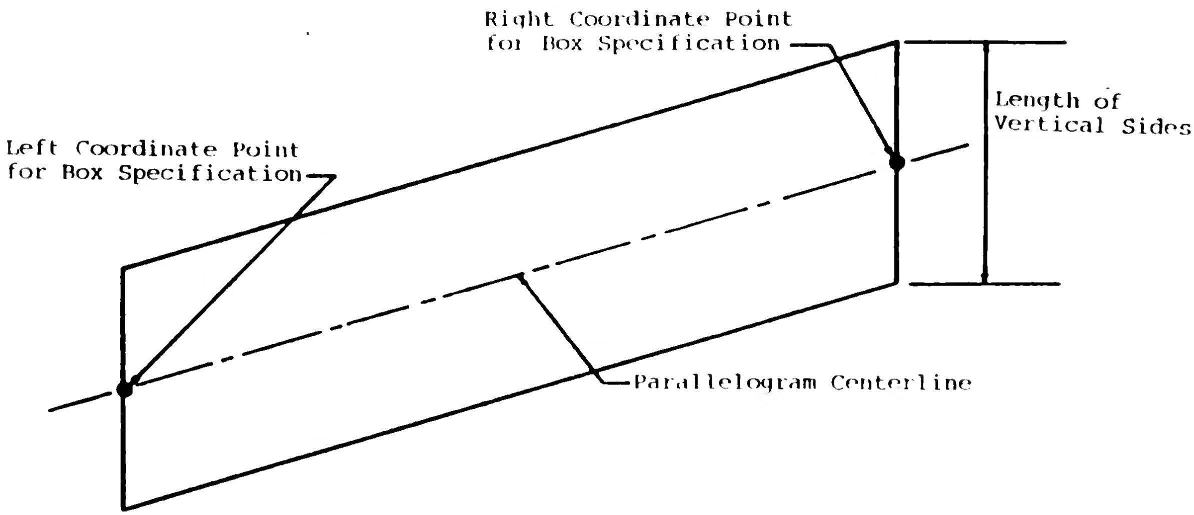


Figure 13: Sliding block box specification.

of the trial surface.

For the active portion of the trail failure surface, a similar process is used with the limits for selection of the random direction being 0 deg and 45 deg with respect to the vertical (Figure 14). The chosen direction is biased towards selection of an angle nearer 45 deg.

A modified version of the sliding block surface generator, named BLOCK2, generates active and passive portions of the sliding block surface according to the Rankine theory. To avoid the problem of the active or passive wedges terminating out of the defined slope boundaries, sketches should be drawn.

Program STABL allows the use of more than two boxes for the formation of the central block (Figure 15). The search may be limited to an irregularly shaped weak zone this way. Another application might be to conduct a search within a zone previously defined as being critical by use of the analysis command RANDOM.

Degenerate cases of parallelogram boxes are permitted. For example, if both points specified as the intersections of a parallelogram centerline with its vertical sides are identical, and the length of the parallelograms vertical sides is non-zero, then a vertical line segment, in effect, is defined. When a trial failure surface is generated, each point along the vertical line segment's length has an equal likelihood of becoming a point defining the surface. The vertical line segment could further degenerate into a point if a zero value is specified for the length of the parallelogram vertical sides. Then all surfaces generated would pass through the single point. One more case of a degenerate parallelogram is a line segment whose inclination and position is that of the parallelogram's centerline. For this case, the length of the vertical sides is zero but the intersections of the parallelogram centerline with its vertical sides are not identical. Again, any point along the length of the line segment has equal likelihood of becoming a point defining a generated trial failure surface.

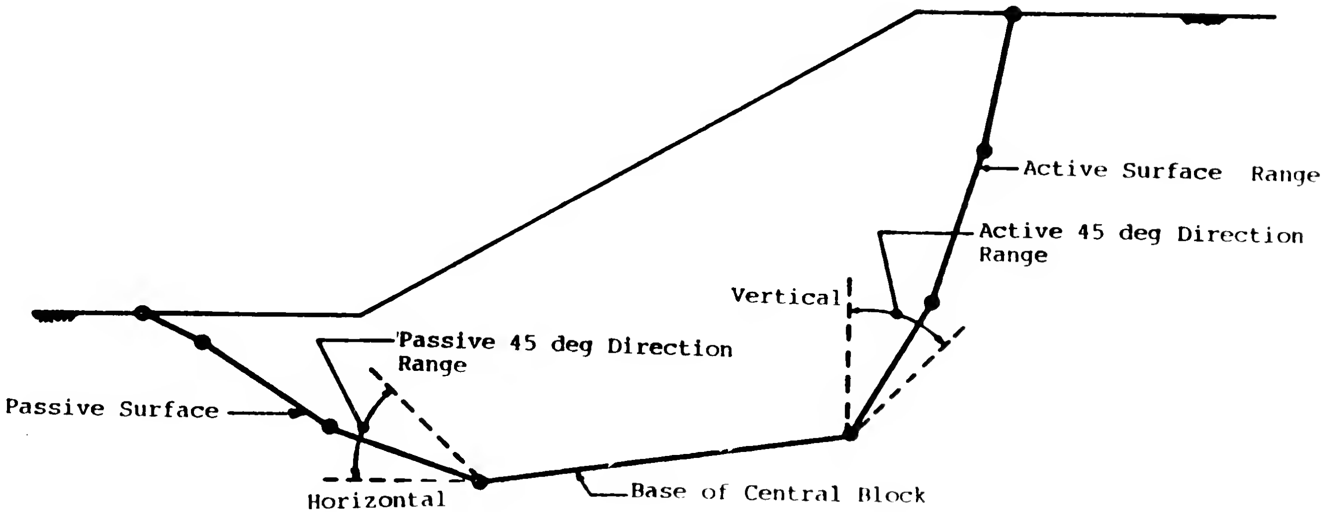
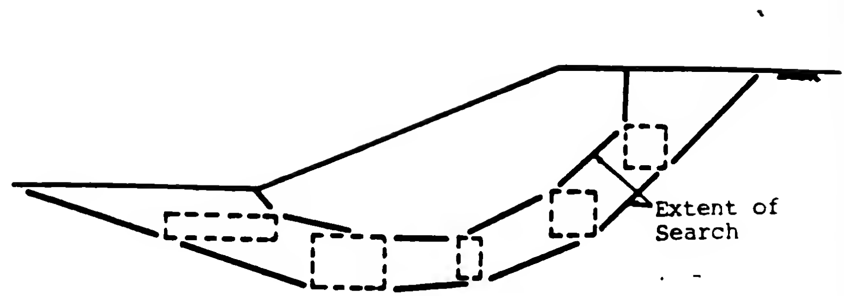
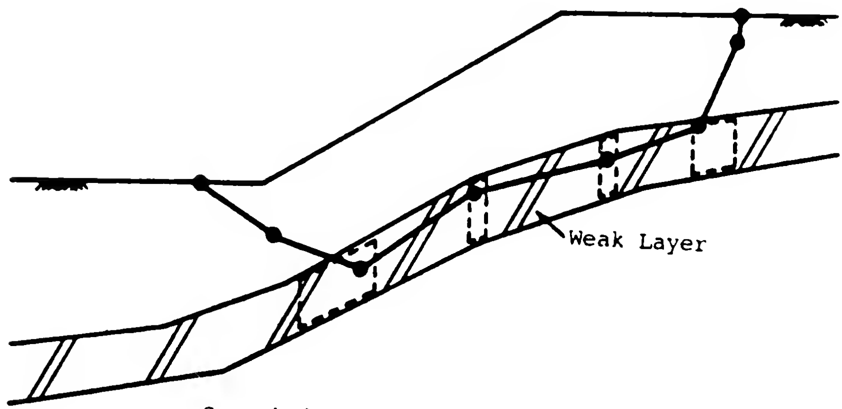


Figure 14: Generation of active and passive sliding surfaces.



Intensive Search of Critical Zone Previously Defined by CIRCLE or RANDOM



Search in Irregular Weak Layer

Figure 15: Sliding block generator using more than two boxes.

Surface Generation Boundaries

As an additional criterion for acceptance of generated trial failure surfaces, an ability to establish boundaries through which a surface may NOT pass has been provided. Such boundaries may be used with all surface generating routines except BLOCK2. Each generation boundary specified is defined by two coordinate points. If a generating surface intersects the line segment defined by the pair of coordinate points, it will either be rejected and a replacement surface will be generated, or the surface will be deflected so that it may be successfully completed. The amount of deflection permitted for a trial failure surface is limited, and when it is insufficient to clear the surface generation boundary intersected, the surface is rejected.

When specifying surface generation boundaries the coordinate points of the left end point should precede those of the right end point. For the case of vertical boundaries, the order is not important. Along with the total number of boundaries, the number of them which deflect generating surfaces upward is specified. The data for these boundaries are required to precede the data for boundaries that deflect downward.

As mentioned previously, a variable elevation bedrock surface can be bounded so that no generated surfaces will pass through the rock. For this case, all the surface generation boundaries defining the bedrock surface would be specified to deflect intersecting trial failure surfaces upward. Another use might occur after a critical zone has been roughly defined by a searching technique. This zone could be bound so that the subsequent search will be completely confined to it. Surface generation boundaries above the zone would be specified to deflect downward, and those below the zone upward.

An important consideration that should be given whenever any type of limitation is imposed for conducting a search for a critical surface is how many generating surfaces are likely to be rejected. A rejected surface is lost effort regardless of how efficiently it was generated by STABL. Perhaps for example, a

multiple box search using command BLOCK would be more efficient than using RANDOM with strict limitations.

Individual Failure Surface

If the failure of the slope is being studied and the location of the actual failure surface is known, STABL offers the option of specifying the known surface as an individual surface for analysis. Another situation for which this option would be useful is when the geologic pattern and shear strength data indicate one or more well defined weak paths along which failure would be expected to occur.

An individual failure surface is approximated by straight line segments defined by a series of points. The end points of the specified trial failure surface are checked for proper location within the horizontal extent of the defined ground surface. The Y coordinates for these two points need not be correctly specified. STABL directs the calculation of the Y coordinate, for each of these two points, from the intersection of a vertical line defined by the specified X coordinate and the ground surface. Data for the coordinate points must be ordered from left to right.

SPENCER'S METHOD OF SLICES

Spencer's method of slices has been incorporated into STABL to enhance the versatility of the program. Spencer's method satisfies both force and moment equilibrium of a sliding mass of soil, whereas the Simplified Janbu and Simplified Bishop methods satisfy only force or moment equilibrium, respectively. Detailed information concerning the derivation, and method of solution of Spencer's method of slices implemented in STABL5M and PCSTABL5M, may be found by referring to:

A. *Carpenter, J.R. (1986), "Slope Stability Analysis Considering Tiebacks and Other Concentrated Loads", MSCE Thesis, Purdue University, West Lafayette, Indiana, 1986.*

B. *Carpenter, J.R. (1985), "STABL5...The Spencer Method of Slices: Final Report", Joint Highway Research Project No. JHRP-85-17, School of Civil Engineering, Purdue University, West Lafayette, Indiana, August, 1985.*

The Spencer option may be invoked by specifying the command "SPENCR" and an estimate of the slope of the interslice forces (One half the user input slope angle is used by the program as an initial estimate of the slope of the interslice forces). The SPENCR command precedes specification of the surface type and method of solution; i.e., SURFAC, SURBIS, CIRCLE, CIRCLE2, RANDOM, BLOCK or BLOCK2.

Since significantly more computation time is required for analysis of potential failure surfaces using Spencer's method of slices tnan either the Simplified Janbu or Simplified Bishop methods, the most efficient use of the STABL5M/PCSTABL5M capabilities will be realized if the user first investigates a number of potential failure surfaces using one of STABL's random surface generation techniques which determines the factor of safety using either the Simplified Janbu or Simplified Bishop method of slices. Once critical potential

failure surfaces have been identified, they may be analyzed using the SPENCR option in conjunction with either the SURFAC or SURBIS option, to obtain a factor of safety (FOS) satisfying both force and moment i.e., complete equilibrium. The reasonableness of the solution obtained may be evaluated through examination of the line of thrust calculated by the Spencer routines.

When a user-input potential failure surface is analyzed, the program outputs the value of the factor of safety with respect to force equilibrium (Ff), the value of the factor of safety with respect to moment equilibrium (Fm), and the angle of the interslice forces (theta) calculated during iteration, along with the value of FOS and theta satisfying complete equilibrium. When a user-input potential failure surface is analyzed, the coordinates of the line of thrust, the ratio of the height of the line of thrust above the sliding surface to the slice height for each slice, and the values of the interslice forces are all output.

The Spencer option may also be used with the STABL options that generate surfaces randomly. However, when the Spencer option is used in conjunction with randomly generated surfaces, only the FOS and angle of the interslice forces satisfying complete equilibrium are output for the ten most critical surfaces. Information regarding the line of thrust, interslice forces or values of Ff, Fm and theta calculated during iteration is not output for randomly generated surfaces; hence the reasonableness of a solution obtained for a randomly generated surface will not be readily apparent. When the reasonableness of the solution of a randomly generated surface is desired, the surface should be analyzed using the SPENCR option in conjunction with either the SURBIS or SURFAC option.

SPENCR Input Restrictions

The only input restrictions require that specification of the "SPENCR" option occur prior to specification of the method of surface generation and solution, i.e., SURFAC, CIRCL2, etc., and the slope angle be greater than zero (deg) and less than or equal to 90 (deg).

TIEBACK LOADS

Introduction

The use of tiebacks in geotechnical engineering and construction for stability of slopes and support of excavations has increased substantially within the last several years. As a result, the need for a method of analyzing the ovefall stability of slopes and retaining walls subjected to horizontal or inclined concentrated loads has become more evident. Before the development of STABL4, the input of horizontal or inclined concentrated loads acting on a near vertical slope was somewhat difficult in STABL. In addition the factor of safety was not formulated for this type of loading and thus, did not fully account for the distribution of force to the failure surface caused by concentrated boundary loads.

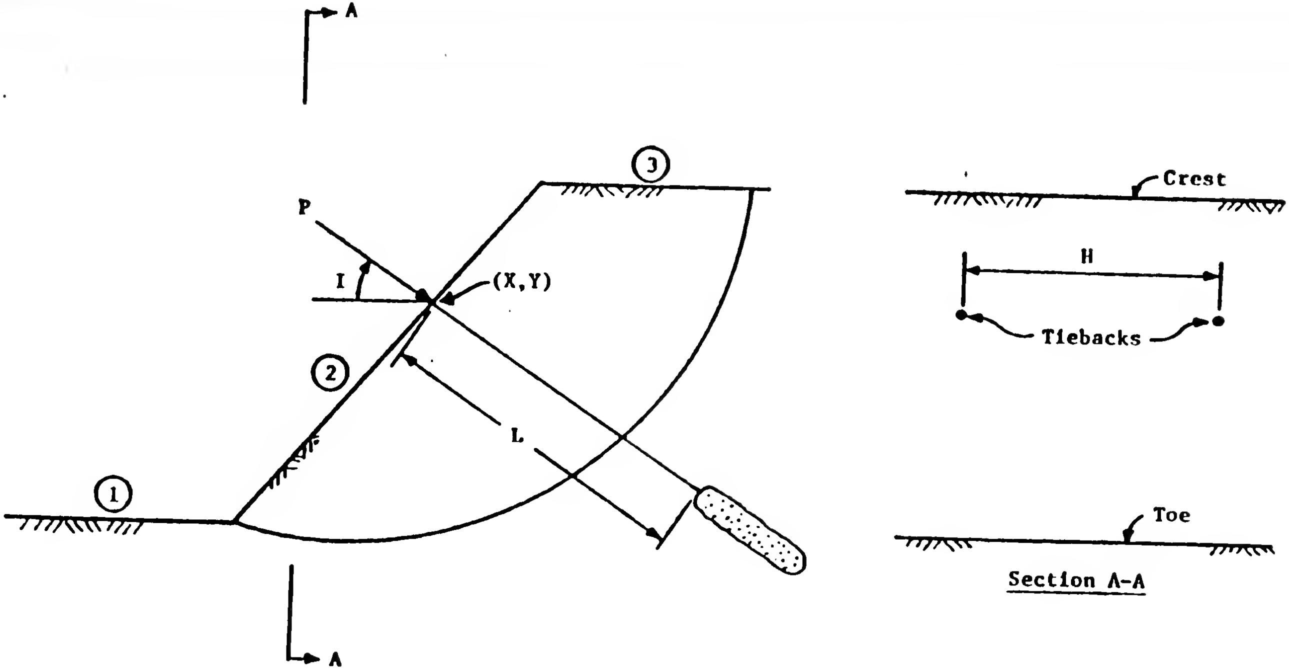
Therefore, to increase the versatility of STABL, new routines have been created within STABL to permit input of horizontal or inclined concentrated loads. These routines were created specifically for the input of tieback loads but may be easily used for any type of concentrated load applied to the ground surface. The latest versions of STABL, (STABL4, STABL5 and STABL5M) contain the new routines which utilize Flamant's Formulas as proposed by Morlier and Tenier (1982), and the simplified Bishop method of analysis for circular failure surfaces, and the simplified Janbu method of analysis for non-circular failure surfaces. In addition, in STABL5 and STABL5M, the Spencer's method of slices can be utilized for both circular and non-circular failure surfaces. The tieback option may be used with either random or specific failure surface generation methods for irregular, block or circular failure surfaces. Throughout this section and within STABL4, STABL5, and STABI 5M the word "tieback" is used to mean tieback or other types of concentrated loads applied to the ground surface.

Tieback (or other types of concentrated loads) are input by specifying the ground surface boundary number where the load is to be applied, the X coordinate of the point of application of the tieback load , the Y coordinate of the

point of application of the tieback load, the load per tieback, the horizontal spacing between tiebacks, the inclination of tieback load as measured clockwise from the horizontal plane, and the free length of tieback (Figure 16). For concentrated boundary loads such as strut loads in a braced excavation, which do not extend into the ground like tiebacks, the length of the tieback is zero. An equivalent line load is calculated for each tieback load specified, assuming a uniform distribution of load horizontally between point loads. The current version of STABL (STABL5M) can allow for the input of concentrated loads applied to a horizontal ground surface boundary, and also allows concentrated loads to be inclined between 0 and 180 degrees from the horizontal.
The input parameters for a tieback load have been changed to also include the input of the X coordinate of the load applied to the ground surface. Previously, only the Y coordinate was required. Either the X coordinate of the point of application of the tieback load can be specified and the Y coordinate calculated, or the Y coordinate can be specified and the X coordinate calculated. If the user desires, both the X and Y coordinates may be input.

If only the X coordinate is specified, a value of zero must be input for the Y coordinate. When the program encounters a zero Y coordinate, it will automatically calculate the proper Y coordinate for the X coordinate and boundary specified. Likewise, if only the Y coordinate is specified, a value of zero must be input for the X coordinate. When the program encounters a zero X coordinate, it will automatically calculate the proper X coordinate for the Y coordinate and boundary specified.

The user may input both the X and Y coordinates of the point of application of the tieback load on the ground surface boundary. However, the coordinates specified must be sufficiently accurate so that the program will recognize an intersection of the X and Y coordinates specified with the ground surface boundary specified. If the difference between the coordinates specified by the user and the coordinates calculated by the program is greater than 0.001, then an error message will be displayed, and the program execution stopped.



Elevation

TIEBACK INPUT PARAMETERS

2	Ground surface boundary number where tieback load is applied
X	X coordinate of point of application (ft) or (m)
Y	Y coordinate of point of application (ft) or (m)
P	Magnitute of load per tieback (lb) or (kg)
H	Horizontal spacing between tiebacks (ft) or (m)
I	Inclination of tieback load (deg)
L	Free length of tieback (ft) or (m)

Figure 16: Tieback input parameters.

A short description of the new tieback routines is presented to help the User understand the method and assumptions used in STABL for analyzing slopes subjected to concentrated loads.

Description of New Tieback Routines

Unlike other slope stability programs, STABL distributes the force from a concentrated load throughout the soil mass to the whole failure surface and hence to all slices of the sliding mass. Other slope stability programs on the other hand, only take a concentrated load into account on the slice on which it acts. This distribution of load throughout the soil mass is a unique feature of STABL.

First an equivalent line load is calculated for a row of tiebacks by dividing the specified tieback load (point load) by the corresponding horizontal spacing between tieback loads. The resulting line load is called TLOAD, (Figure 17), and is inclined from the horizontal by an angle INCLIN. The radial stress on the midpoint of a slice is calculated using Flamant's Formula (Morlier and Tenier, 1982):

$$\sigma_r = \frac{2(TLOAD)\cos(TTHETA)}{\pi(DIST)}$$

where:

σ_r	Radial stress
TLOAD	Equivalent tieback line load
TTHETA	Angle between the line of action of the tieback and the line between the point of application of the tieback on the ground surface and the midpoint of the slice.
π	pi
DIST	Distance between the point of application of the tieback on the ground surface and the midpoint of the slice.

The radial force, PRAD, at the midpoint of the base of the slice due to the concentrated load is calculated by multiplying the radial stress by the length of

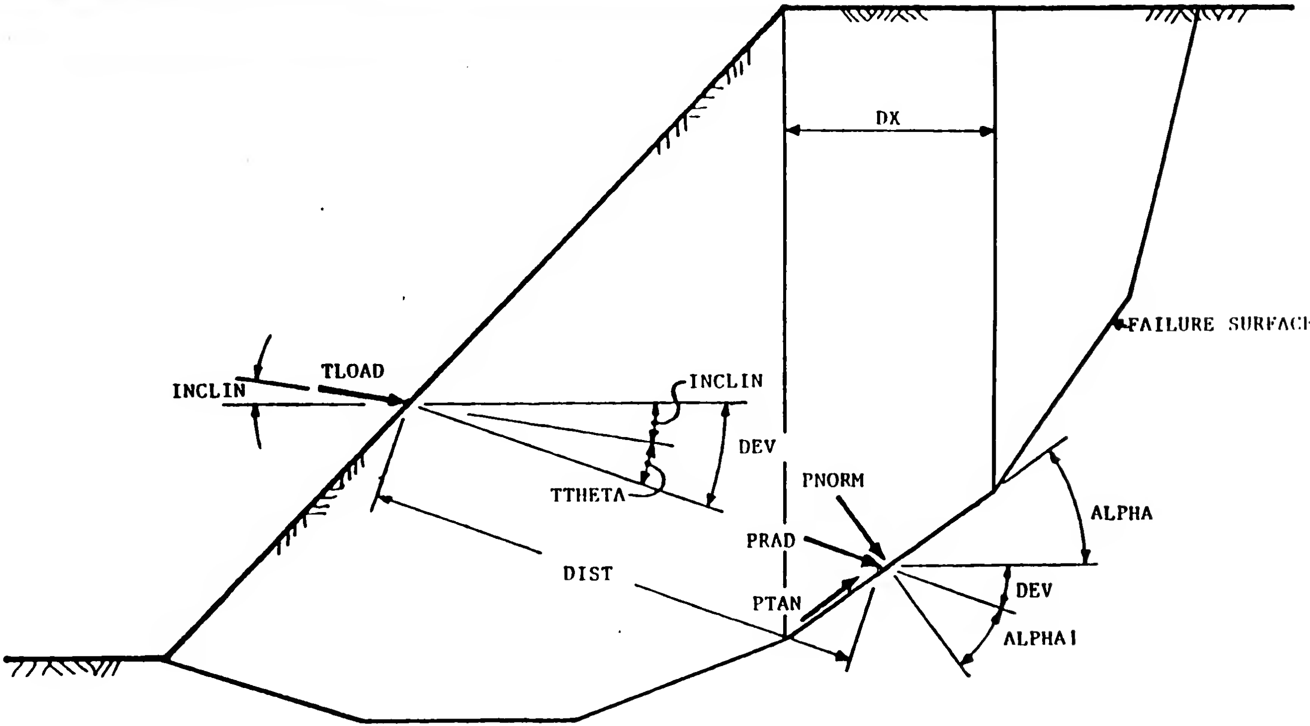


Figure 17: Transfer of concentrated load to failure surface.

the base of the slice:

$$PRAD=\frac{2(TLOAD)\cos(TTHETA)(DX)}{\pi(DIST)\cos(ALPHA)}$$

where:

PRAD	Radial force on base of slice due to concentrated load.
ALPHA	Inclination of base of slice
DX	Slice width

Note that the radial stress produced on the base of the slice by the concentrated load is proportional to the load applied (TLOAD) and the width of the slice (DX), inversely proportional to the distance between the point of application of the load and the midpoint of the base of the slice (DIST), and dependent upon the angle between the line of action of the load and the line between the point of application of the load and the midpoint of the base of the slice (TTHETA). Therefore, slices which are in line with the direction of the concentrated load will receive a larger portion of the total load than will slices which are farther away and whose angle TTHETA is large.

The radial force PRAD is distributed in the same manner to all the slices of the sliding mass. The radial forces on all the slices are then summed in the direction of the concentrated load, PSUM, and compared with the applied load, TLOAD. Since the sum of radial forces for a failure surface, PSUM, is not always exactly equal to the applied load, due to slope geometry and the shape of the failure surface, the radial force applied to the base of each slice is modified as follows:

$$PRAD=TLOAD/PSUM$$

The refined radial force for each slice, PRAD, is broken into its components normal and tangential to the base of the slice for calculation of the factor of safety. The normal and tangential components of the force due to the concentrated load are respectively:

$$PNORM=(PRAD)\cos(ALPHA1)$$

$$PTAN=(PRAD)\sin(ALPHA1)$$

The same process is repeated for all additional rows of tiebacks. The sum of the normal components and the sum of the tangential components due to all rows of tiebacks are then used in the slice equilibrium equations for calculating the factor of safety.

There is a special case where the tieback loads will not be distributed to quite all the slices of the sliding mass and is shown in Figure 18. Figure 18 shows the limit of the stress distribution for a benched slope. The force due to the applied load is not distributed to the slices of the far left or the slices of the far right since this would require distribution of load through air and not the soil mass.

TIES input Restrictions

1. The point of application of a tieback on the ground surface may not be at a ground surface boundary node. Use a slight offset from the node, (i.e. 70.01 instead of 70).

2. No more than 10 tieback loads can be specified: however, they can be in any order.

3. The inclination of a tieback must be equal to or greater than zero degrees and less than 180 degrees as measured clockwise from the horizontal.

4. The horizontal spacing between tiebacks must be greater than or equal to 1 ft (or 1 meter if using SI units).

5. The length of a tieback must be equal to or greater than zero ft. Zero is used for loads other than tieback type of loads.

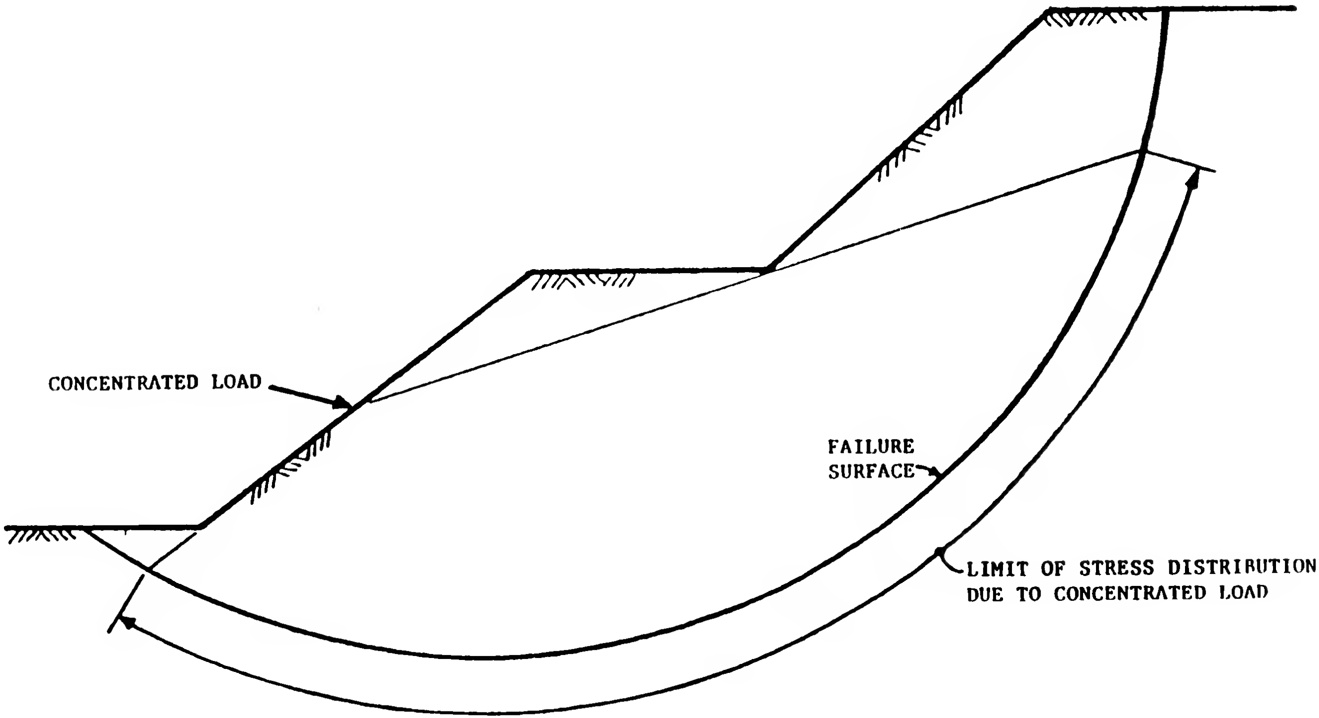


Figure 18: Limit of stress distribution due to concentrated load.

DATA PREPARATION

A primary goal during the development of program STABL, was to maintain a simple format for data preparation and input. This was felt to be very important because much time can be consumed getting the "bugs" out of the input data, especially by a new or occasional user.

In an attempt to reduce preparation errors and debugging time, STABL has four helpful features: (1) problem oriented language; (2)free-form data input; (3) execution time data consistency checking; and (4) graphical display of input and output geometry data. These features will be discussed in following sections.

Problem Oriented Language

This feature allows the selection, by command, of only those portions of STABL which are required to solve a particular problem. It also provides flexibility in problem modification for additional analyses during a single execution of STABL.

Below are listed the commands understood by STABL and their primary functions. There are essentially two types; data commands and analysis commands.

Data Commands:

PROFIL initiate problem; read and store boundary data defining ground surface and subsurface material interfaces.

SOIL read, check, and store isotropic soil parameter

data.

ANISO read, check, and store anisotropic strength parameter data.

WATER read, check and store data defining piezometric surfaces.

SURFAC or

SURBIS read, check, and store data defining a single trial failure surface (SURBIS only for circular shaped failure surfaces).

LOADS read, check, and store data defining surface boundary surcharge loads.

EQUAKE read and store pseudo-static earthquake coefficients and cavitation pressure.

LIMITS read, check, and store data defining surface generation boundaries.

TIES read, check, and store data defining tieback loads.

Analysis Commands:

EXECUT calculate factor of safety for single specified trial failure surface.

CIRCLE or

CIRCL2 generate circular surfaces and determine critical surfaces.

RANDOM generate irregular surfaces and determine critical surfaces.

BLOCK or *BLOCK2* generate sliding block surfaces and determine critical surfaces.

SPENCR analyses circular, and irregular surfaces according to Spencer's method.

The data commands primary functions are to read data pertinent to the definition of a particular slope stability problem, to check the data for consistency with program requirements, and to store these data for subsequent use by the analysis commands.

The analysis commands primary purpose is analysis of the problem in some manner using previously stored data. One such way is the analysis of a single trial failure surface previously defined by the data command SURFAC. Another way is to generate potential failure surfaces, searching for the critical surfaces, using one or more of the surface generation techniques.

General Rules for Use of Commands

All commands may be used as often as desired, however, there are some restrictions that are imposed regarding sequencing them for execution.

Once a data command is invoked, the data, stored as a result, remain in effect until replacement or suppression is effected by another usage of the same command. There are two exceptions to this. The first concerns the use of command PROFIL. The command prepares STABL for a new problem by

defining a new profile. As a result, all data, which may have been stored by previous usages of other data commands in the execution sequence, will be lost. Incidentally, PROFIL is required to be the first command in the execution sequence. The second exception involves use of the analysis commands CIRCLE, BLOCK, RANDOM, and SPENCR . Use of these commands will destroy the trial failure surface data stored by command SURFAC.

Temporary suppression of data previously stored by any of the commands WATER, LOADS, LIMITS, ANISO, and TIES is accomplished by a special use of each command. Each of the commands require that the number of repetitive data sets be specified. By specifying zero, STABL is instructed to suppress all data pertinent to the particular command used. While suppressed, the data are not available for use by the analysis commands. The data will remain suppressed until reactivated by a second use of the same command with zero specified. If new data are read and stored while old data are suppressed, the old data are lost for further use.

Isotropic soil parameters may be modified by specifying the number zero and the number of soil types which are to be changed. Then the soil type number and appropriate soil parameters are specified for each soil type modified.

Use of the analysis commands requires, as a minimum, definition of a problem profile and the soil parameters. In addition, use of the analysis command EXECUT requires definition of a specific trial failure surface.

Below is an example of how some commands might be sequenced.

PROFIL	.. data (1)	
SOIL	.. data (2)	
SURFAC	.. data (3)	
EXECUT		Factor of safety calculation with data (1), (2), and (3).
WATER	.. data (4)	

EXECUT		Factor of safety calculation with data (1), (2), (3), and (4).
SURFAC	.. data (5)	Replaces data (3) with data (5).
EQUAKE	.. data (6)	
EXECUT		Factor of safety calculation with data (1), (2), (4), (5), and (6).
WATER	.. suppress data (4)	
EXECUT		Factor of safety calculation with data (1), (2). (5). and (6).
WATER	.. reactivate data (4)	
EQUAKE	.. data (7)	Replace data (6) with data (7).
EXECUT		Factor of safety calculation with data (1). (2). (4). (5). and (7).
PROFIL	.. data (8)	Nullifies all previous data-initiates new problem.
EQUAKE	.. data (9)	
SOIL	.. data (10)	
SURFAC	.. data (11)	
EXECUT		Factor of safety calculation with data (8), (9), (10), and (11).

Free-Form Data Input

A primary goal during the development of STABL, was to simplify its use regardless of its complexity. This was felt to be very important because many unsuccessful attempts to use computer programs are largely due to faulty preparation of data, which is generally the result of confusing program requirements. Another source of abortive attempts are rigid requirements for proper placement of data items within specific format fields, e.q., integers right adjusted.

To ease requirements of data input, a method for reading numbers free-form has been incorporated within STABL. This method is especially useful when typing data with a monitor.

Typing Instructions for Free-Form Data Input

Create an input file using any convenient editor commencing with the first column. This file will contain all the required commands and data to run the program. When the computer cannot match your command with one which STABL has been programmed to recognize, your command will be displayed with an error message as output and execution will be terminated. Be certain the spelling of each command is correct.

One and only one blank space should separate each subsequent data item on a card. STABL directs the computer to read data from the next line when two or more blank spaces are encountered. If a gap of more than one blank space occurs between two adjacent data items, all data items on the line following the gap will not be read. Instead, data on the following line will be read next. If unintentional, a shift in all data subsequently read will occur. Eventually, an indirect error will be generated. Most likely is a situation where a real number is read as an integer or vice versa.

An integer is a whole number generally used for counting, while a real number is a rational number used for measurement of magnitude. STABL requires that an integer contains no decimal point, while a real number must.

For the problem description associated with the data command PROFIL, any combination of alpha-numeric characters, blanks, and special characters may be used within the eighty columns of one card. The description will appear on two lines as printed output of forty columns each, so the description should be written accordingly.

Input for each Command

The data for each command and their organization are outlined below. A new line of data should be started, wherever a data card or command card is encountered.

INPUT FOR PROFILE

COMMAND CARD	PROFIL	Command Code
DATA CARD	Title	
DATA CARD	Integer	Total number of boundaries
	Integer	Number of surface boundaries
DATA CARD	Real	X coordinate of left end of boundary (ft)
	Real	Y coordinate of left end of boundary (ft)
	Real	X coordinate of right end of boundary (ft)
	Real	Y coordinate of right end of boundary (ft)
	Integer	Soil type index number for material immediately beneath boundary.

NOTE: Repeat proceeding data card for each boundary.

INPUT FOR SOIL TYPES

COMMAND CARD	SOIL	Command Code
DATA CARD	Integer	Number of soil types
DATA CARD	Real	Moist unit weight (pcf)
	Real	Saturated unit weight (pcf)
	Real	Isotropic strength intercept (pcf)
	Real	Isotropic strength angle (deg)
	Real	Pore pressure parameter
	Real	Pore pressure constant (pcf)
	Integer [1]	Piezometric surface number

NOTE: Repeat proceeding data card for each soil type.

INPUT FOR MODIFYING SOIL TYPES
(if specified)

COMMAND CARD	SOIL	Command Code
DATA CARD	Integer	Number zero (0)
	Integer	Number of soil types to be modified
DATA CARD	Integer	Soil type number
	Real	Moist unit weight (pcf)
	Real	Saturated unit weight (pcf)
	Real	Isotropic strength intercept (psf)
	Real	Isotropic strength angle (deg)
	Real	Pore pressure parameter
	Real	Pore pressure constant (psf)
	Integer	Piezometric surface number

NOTE: Repeat proceeding data card for each soil type modified.

INPUT FOR STRENGTH ANISOTROPY
(if specified)

COMMAND CARD	ANISO	Command Code
DATA CARD	Integer	Number of anisotropic soil types
DATA CARD	Integer	Soil type index number
	Integer	Number of directional strength parameter data sets

NOTE: Repeat proceeding data card and the following set of data cards for

1 If no piezometric surface is specified, any number can be used

each anisotropic soil type.

DATA CARD	Real	Counterclockwise direction limit (deg)
	Real	Strength intercept (psf)
	Real	Strength angle (deg)

NOTE: Repeat proceeding data card for each range of direction

INPUT FOR SUPPRESSING OR REACTIVATING STRENGTH ANISOTROPY (if specified)

COMMAND CARD	ANISO	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR WATER SURFACE (if specified)

COMMAND CARD	WATER	Command Code
DATA CARD	Integer	Number of piezometric surfaces defined
	Real	Unit weight of water[2]

NOTE: Repeat the following set of data cards for each piezometric surface.

DATA CARD	Integer	Number of points defining the water surface
DATA CARD	Real	X coordinate of point on water surface (ft)

2. If 0. is specified, 62.4 (pcf) is assumed.

	Real	Y coordinate of point on water surface (ft)

NOTE: Repeat proceeding data card for each point on the water surface.

INPUT FOR SUPPRESSING OR REACTIVATING WATER SURFACE (if specified)

COMMAND CARD	WATER	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR BOUNDARY LOADS (if specified)

COMMAND CARD	LOADS	Command Code
DATA CARD	Integer	Number of boundary loads
DATA CARD	Real	X coordinate of left end of boundary load (ft)
	Real	X coordinate of right end of boundary load (ft)
	Real	Intensity of boundary load (psf)
	Real	Angle of inclination of boundary load- positive counterclockwise from vertical (deg)

NOTE: Repeat proceeding data card for each boundary load.

INPUT FOR SUPPRESSING OR REACTIVATING BOUNDARY LOADS (if specified)

COMMAND CARD	LOADS	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR EARTHQUAKE LOAD
(if specified)

COMMAND CARD	EQUAKE	Command Code
DATA CARD	Real	Earthquake coefficient for horizontal acceleration (defined positive outwards from face of slope)
	Real	Earthquake coefficient for vertical acceleration (defined positive upwards)
	Real	Cavitation pressure (psf)

INPUT FOR SPECIFIC FAILURE SURFACE
(if specified)

COMMAND CARD	SURFAC	Command Code (or *SURBIS*[4])
DATA CARD	Integer	Number of points defining the failure surface
DATA CARD	Real	X coordinate of point on failure surface
	Real	Y coordinate of point on failure surface

NOTE: Repeat proceeding data card for each point on the failure surface.

3. Negative values may be specified.
4. SURBIS for circular surfaces, Modified Bishop Factor of Safety

INPUT FOR ANALYSIS OF SPECIFIED TRIAL SURFACE
(if specified)

COMMAND CARD	EXECUT	Command Code

INPUT FOR TRIAL SURFACE GENERATION LIMITS
(if specified)

COMMAND CARD	LIMITS	Command Code
DATA CARD	Integer	Total number of generation boundaries
	Integer	Number of generation boundaries which deflect upward
DATA CARD	Real	X coordinate of left end of generation boundary (ft)
	Real	Y coordinate of left end of generation boundary (ft)
	Real	X coordinate of right end of generation boundary (ft)
	Real	Y coordinate of right end of generation boundary (ft)

NOTE: Repeat proceeding card of each generation boundary.

INPUT FOR SUPPRESSING OR REACTIVATING TRIAL SURFACE GENERATION LIMITS
(if specified)

COMMAND CARD	LIMITS	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR CIRCULAR SURFACE SEARCHING.
(if specified)

JANBU METHOD

COMMAND CARD	CIRCLE	Command Code
DATA CARD	Integer	0 or 1 (No or Yes). To using Janbu's empirical coefficient
	Integer	Soil fits (if above is 1): 1 - $\phi = 0$ 2 - c & ϕ both > 0 3 - c=0
DATA CARD	Integer	Number of initiation points
	Integer	Number of surfaces to be generated from each initiation point
DATA CARD	Real	X coordinate of leftmost initiation point (ft)
	Real	X coordinate of rightmost initiation point (ft)
	Real	X coordinate of left termination limit (ft)
	Real	X coordinate of right termination limit (ft)
DATA CARD	Real	Minimum elevation of surface development (ft)
	Real	Length of segments defining surfaces (ft)

	Real	Counterclockwise direction limit for surface initiation (deg)
	Real	Clockwise direction limit for surface initiation (deg)

BISHOP METHOD

COMMAND CARD	CIRCL2	
DATA CARD	Integer	Number of initiation points
	Integer	Number of surfaces to be generated from each initiation point
DATA CARD	Real	X coordinate of leftmost initiation point (ft)
	Real	X coordinate of rightmost initiation point (ft)
	Real	X coordinate of left termination limit (ft)
	Real	X coordinate of right termination limit (ft)
DATA CARD	Real	Minimum elevation of surface development (ft)
	Real	Length of segments defining surfaces (ft)
	Real	Counterclockwise direction limit for surface initiation (deg)
	Real	Clockwise direction limit for surface initiation initiation.

INPUT FOR IRREGULAR SURFACE SEARCHING
(if specified)

COMMAND CARD	RANDOM	Command Code
DATA CARD	Integer	0 or 1 (No or Yes) To using Janbu's empirical coefficient
	Integer	Soil fits (if above is 1):
		1 - $\phi = 0$
		2 - c & ϕ both > 0
		3 - $c=0$
DATA CARD	Integer	Number of initiation points
	Integer	Number of surfaces to be generated from each initiation point
DATA CARD	Real	X coordinate of leftmost initiation point (ft)
	Real	X coordinate of rightmost initiation point (ft)
	Real	X coordinate of left termination point (ft)
	Real	X coordinate of right termination point (ft)
DATA CARD	Real	Minimum elevation of surface development (ft)
	Real	Length of segments defining surfaces (ft)
	Real	Counterclockwise direction limit for surface initiation (deg)
	Real	Clockwise direction limit for surface initiation (deg)

INPUT FOR BLOCK SURFACE SEARCHING
(if specified)

COMMAND CARD	BLOCK	Command Code (or *BLOCK2*[5])
DATA CARD	Integer	0 or 1 (No or Yes) To using Janbu's empirical coefficient
	Integer	Soil fits (if above is 1): 1 - $\phi = 0$ 2 - c & ϕ both > 0 3 - c=0
DATA CARD	Integer	Total number of surfaces to be generated
	Integer	Number of boxes used to generate base of central block
	Real	Length of segments defining surfaces (ft)
DATA CARD	Real	X coordinate of left end of centerline defining the box (ft)
	Real	Y coordinate of left end of centerline defining the box (ft)
	Real	X coordinate of right end of centerline defining the box (ft)
	Real	Y coordinate of right end of centerline defining the box (ft)
	Real	Length of vertical side of the box (ft)

NOTE: Repeat proceeding data card for each box.

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5 BLOCK2 is a sliding block surface generator modified from BLOCK, the difference being that BLOCK2 generates active and passive portions of the sliding blocks according to the Rankine theory, where BLOCK generates these more randomly

INPUT FOR TIES

COMMAND CARD	TIES	Command Code
DATA CARD	Integer	Number of tieback loads
DATA CARD	Integer	Boundary number where tieback load is applied
	Real	X coordinate of the point of application of tieback load (ft) or (m)
	Real	Y coordinate of the point of application of tieback load (ft) or (m)
	Real	Load per tieback (lbs) or (kg)
	Real	Horizontal spacing between tiebacks (ft) or (m)
	Real	Inclination of tieback load as measured clockwise from the horizontal plane (deg)
	Real	Free length of tieback (ft) or (m) (Equal to zero if other than a tieback load)

NOTE: Repeat preceding data card for each tieback load.

INPUT FOR SUPPRESSING OR REACTIVATING TIEBACK LOADS. (if specified)

COMMAND CARD	TIES	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR SPENCR

COMMAND CARD	SPENCR	Command Code
DATA CARD	Real	Estimate of approximate slope angle with respect to horizontal (deg)

ERROR MESSAGES

STABL is intended to be error free, assuming that the input data are correctly prepared. To avoid problems when the data have been incorrectly prepared, STABL checks all data, as they are being read in, for consistency with program requirements.

If an inconsistency is found in data submitted, STABL points it out by displaying an error indication. Unless the error is of a nature that demands immediate termination of execution, STABL continues reading data and checking for more errors until a point is reached in execution where termination is required as a consequence of previously determined errors.

The errors are coded and referenced to descriptions in the next section. Each input error has a two digit number prefixed with two letters, associating the error with a particular command or class of errors. The prefixes are listed below.

SQ - Command Sequence errors
FR - Free-form Reader errors
PF - errors associated with command PROFIL
WA - errors associated with command WATER
SF - errors associated with command SURFAC
LM - errors associated with command LIMITS
LD - errors associated with command LOADS
SL - errors associated with command SOIL
AI - errors associated with command ANISO
RC - errors associated with commands RANDOM and CIRCLE
BK - errors associated with command BLOCK
TI - errors associated with command TIES
SP - errors associated with command SPENCR

Command Sequence Errors

SQ01- A command other than PROFIL has been used as the first command in the execution sequence. The first command must be PROFIL. PROFIL initializes STABL prior to reading all data pertinent to the definition of a problem. All data that would have been read prior to encountering the first use of command PROFIL would have been nullified and would not have been made available to STABL for the purpose of analyzing the first problem.

SQ02- An attempt to compute the factor of safety of a specified trial failure surface with command EXECUT has been aborted. The isotropic soil parameters describing the soil types of the current problem do not exist. After each use of the command PROFIL in an execution sequence, the isotropic soil parameters of each soil type must be specified by use of command SOIL before command EXECUT may be used. Each time a new problem is introduced in an execution sequence by command PROFIL, the soil parameters describing soil types of preceding problems are no longer available for use.

SQ03- An attempt to compute the factor of safety of an unspecified trial failure surface with command EXECUT has been aborted. After each use of command PROFIL, CIRCLE, RANDOM or BLOCK, a trial failure surface must be specified with command SURFACE before command EXECUT may be used.

SQ04- The command ANISO has been used without the isotropic soil parameters being defined. Anisotropic strength data may not be specified unless the isotropic parameters have been defined by command SOIL after the last use of command PROFIL.

SQ05- An attempt to use one of the commands, RANDOM, CIRCLE, or

BLOCK has been aborted. The isotropic soil parameters describing the soil types of the current problem do not exist. After each use of command PROFIL in an execution sequence, the isotropic soil parameters of each soil type must be specified by use of command SOIL before any of the above mentioned commands may be used. Each time a new problem is introduced in an execution sequence by command PROFIL, the soil parameters describing soil types of preceding problems are no longer available for use.

Free-form Reader Error Codes

FR01- Data are insufficient to continue execution. An attempt was made to read beyond the last data item specified. Check for missing data items or for gaps between data items on each line larger than one blank space. This error only occurs at the end of an execution sequence within the data provided with the last command used.

FR02- The line of data displayed begins with one or more blank spaces or may be entirely blank. The first item of data of each line is required to begin in the first column. Lines entirely blank are not permitted.

FR03- Within the line of data displayed, a decimal point has been detected for a number read as an integer. An integer is not allowed to contain a decimal point. First check if any numbers intended to be integers contain a decimal point. If not, check if error is indirectly caused by a displacement of data read. Causes of displacements are discussed below.

FR04- Within the line of data displayed, a minus sign has been detected for a number read as an integer. All integers are required to be positive. Negative integers are never required as input for STABL. This error may be caused indirectly by displacement of data read. Causes of displacements are discussed below.

FR05- Within the line of data displayed, an illegal character has been detected for a number read as an integer. Only numeric characters and decimal points are allowed. If a command word is displayed, the data provided with the previous command was not sufficient to complete its execution. Check for a displacement of data read. Causes of displacements are discussed below.

FR06- Within the line of data displayed, a decimal point was not detected for a number read as a real number. A real number is required to contain a decimal point. First check if any numbers intended to be real numbers lack decimal points. If not, check if error is indirectly caused by a displacement of data read. Causes of displacements are discussed below.

FR07- Within the line of data displayed, an illegal character has been detected for a number read as a real number. Only numeric characters, decimal point, and minus sign are allowed. If a command word is displayed, the data provided with the previous command was not sufficient to complete its execution. Check for a displacement of data read. Causes of displacements are discussed below.

Displacements of data read are caused either by inadvertently omitting items of data or by leaving gaps between items of data larger than one blank space. Data items following a gap larger than one blank space are not read. Instead, data from the next line are read in their place, producing a displacement of data read from that point on.

At some point following the displacement, an error will be produced indirectly. A real number might be read as an integer, or vice versa, producing error FR03 or FR06 respectively. A negative real number read as an integer will also produce error FR04. When a displacement occurs, and if none of the above errors are produced, the numeric data will be exhausted and finally a command word will be read as numeric data producing error FR05 or FR07 depending upon whether an integer or real number was being read.

If cause of displacement is not found in the displayed line of data, check the preceding lines of data.

PROFIL Error Codes

PF01- The number of ground surface boundaries exceeds the total number of profile boundaries. The number of profile boundaries must be less than or equal to the total number of profile boundaries.

PF02- The number of profile boundaries specified may not exceed 100. The problem must be either redefined so fewer profile boundaries are used, or the dimensioning of the program must be increased to accommodate the problem so defined.

PF03- A negative coordinate has been specified for the profile boundary indicated. All problem geometry must be located within the 1st quadrant.

PF04- The coordinates of the end points of the profile boundary indicated have not been specified in the required order. The coordinates of the left end point must precede those of the right

PF05- The ground surface boundaries indicated are not properly ordered or are not continuously connected. The ground surface boundaries must be specified from left to right and the ground surface described must be continuous.

PF06- The required subsurface boundary order is unsatisfied for the boundaries indicated. Of boundaries which overlap horizontally, those above the others must be specified first.

WATER Error Codes

WA01- An attempt has been made to suppress or reactivate undefined water surface data. Data must be defined by a prior use of command WATER before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data prior to their use whether the data are active or suppressed.

WA02- The number of points specified to define the water surface exceeds 40. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

WA03- Only one point has been specified to define the water surface. A minimum of two points is required.

WA04- A negative coordinate has been specified for the water surface point indicated. All problem geometry must be located within the 1st quadrant.

WA05- The water surface point indicates that it is not to the right of the points specified prior to it. The points defining the water surface must be specified in left to right order.

SURFAC Error Codes

SF01- The number of points specified to define a trial failure surface exceeds 100. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

SF02- Only one point has been specified to define the trial failure surface.

A minimum of two points is required.

SF03- A negative coordinate has been specified for the trial failure surface point indicated. All problem geometry must be located within the first quadrant.

SF04- The trial failure surface point indicated is not to the right of the points specified prior to fit. The points defining the trial failure surface must be specified in left to right order, and no two points are allowed to define a vertical line.

SF05- The first point specified for the trial failure surface is not within the horizontal extent of the defined ground surface. All points defining a trial failure surface must be within the horizontal extent of the defined ground surface.

LIMITS Error Codes

LM01- An attempt has been made to suppress or reactivate undefined surface generation boundary data. Data must be defined by a prior use of command LIMITS before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use whether the data are active or suppressed.

LM02- The number of surface generation boundaries specified to deflect upwards exceeds the total number of boundaries specified. The number of upward deflecting boundaries must not exceed the total number of boundaries.

LM03- The number of surface generation boundaries specified exceeds 20. The problem must be either redefined so fewer surface generation boundaries are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

LM04- A negative coordinate has been specified for the surface generation boundary indicated. All problem geometry must be located within the 1st quadrant.

LM05- The coordinates of the end points of the surface generation boundary indicated have not been specified in the required order. The coordinates of the left end point must precede those of the right.

LOADS Error Codes

LD01- An attempt has been made to suppress or reactivate undefined surcharge boundary loads. Data must be defined by a prior use of command LOADS before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use, whether the data are active or suppressed.

LD02- The number of surcharge boundary loads specified exceeds 10. The problem must be either redefined so fewer loads are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

LD03- A negative coordinate has been specified for the surcharge boundary load indicated. All problem geometry must be located within the first quadrant.

LD04- The X coordinates defining the horizontal extend of the surcharge boundary load indicated have not been specified in the required order. The X coordinate of the left end of the load must precede the X coordinate of the right end.

LD05- The surcharge boundary load indicated is not to the right of all the loads specified prior to it or overlaps one or more of them. The loads must be specified left to right and are not allowed to overlap.

SOIL Error Codes

SL01- The profile boundary indicated with the error message has an undefined soil type index. The number of soil types specified must be greater than or equal to each soil type index which has been assigned to profile boundaries.

SL02- The number of soil types may not exceed 20. The problem must be either redefined so fewer soil types are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

SL03- An attempt has been made to change the parameters of one or more soil types which are undefined. No soil types have been defined since the last use of command PROFIL. When a new problem is introduced by command PROFIL, the soil parameters, describing soil types of preceding problems in the execution sequence, are no longer available for use and cannot therefore be changed.

SL04- The number of soil types to be changed is greater than the total number of soil types already defined. This implies changing isotropic soil parameters of soil types which have not been specified and therefore is not permitted. The number of soil types to be changed must be less than or equal to the number of soil types specified by a previous use of command

SOIL. Each soil type must be previously specified, before its parameters may be changed.

SL05- An attempt has been made to change the parameters describing an unspecified soil type. The soil type must be defined before it may be modified. The index of each soil type to be changed must be less than the total number of soil types.

ANISO Error Codes

AI01- An attempt has been made to suppress or reactivate undefined anisotropic strength data. Data must be defined by a prior use of command ANISO before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use whether the data are active or suppressed.

AI02- The number of anisotropic soil types specified may not exceed the number of soil types specified by command SOIL.

AI03- The number of anisotropic soil types specified exceeds 5. The problem must be either redefined so fewer anisotropic soil types are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

AI04- The soil type index indicated is greater than the number of soil types specified by command SOIL. The index of each anisotropic soil type must be less than or equal to the number of soil types specified.

AI05- The number of direction ranges specified for the anisotropic soil type

indicated is less than 2 or exceeds 10. No soil type should be defined anisotropic with number of direction ranges less than 2, as this means soil is isotropic. Also no soil type should exceed 10 direction ranges. If this is desired, the dimensions of the program must be increased.

AI06- The counterclockwise limit of each direction range must be specified in counterclockwise order, if the anisotropic strength is to be properly defined for the anisotropic soil type indicated.

AI07- The total direction range for the anisotropic soil type indicated has not been competely defined. The counterclockwise limit of the last direction range specified must be 90 degrees.

RANDOM and CIRCLE Error Codes

RC01- The first initiation point lies to the left of the defined ground surface. The x coordinate of the first initiation point must be specified so all trial failure surfaces generated will intersect the defined ground surface when they initiate.

RC02- The first and last initiation points are not correctly specified. They must be specified in left-right order.

RC03- The last initiation point lies to the right of the defined ground surface. The X-coordinate of the last initiation point must be specified so all trial failure surfaces generated will intersect the defined ground surface when they initiate.

RC04- The right termination limit lies to the right of the defined ground surface. The right termination limit must be specified so all trial failure

surfaces generated will intersect the defined ground surface when they terminate.

RC05- The left and right termination limits are not correctly specified. They must be specified in left-right order.

RC06- The last initiation point lies to the right of the right termination limit. It is impossible to successfully generate any trial failure surfaces, when the initiation point lies to the right termination limit.

RC07- The depth limitation for trial failure surface development is negative. The depth limitation must be set at or above the X-axis so the generated trial failure surfaces will not be allowed to develop below it.

RC08- The length specified for the line segments used to generate trial failure surfaces is less than or equal to zero. The length must be greater than zero.

RC09- An initiation point is below the depth initiation. The depth limitation must be set lower to enable the successful generation of trial failure surfaces from all initiation points.

RC10- The number of points defining a generated trial failure surface exceeds 100. The length specified for the line segments must be increased.

RC11- 200 attempts to generate a single trial failure surface have failed. The search limitations are either too restrictive, or they actually prevent successful generation of a trial failure surface from one or more of the initiation points. Check and revice the search limitations or use an alternative trial surface generator.

RC12- Fewer than 10 trial surfaces have been specified to be generated. A minimum of 10 must be generated.

RC13- The angle specified as clockwise direction limit for surface generation is larger than the angle specified as counterclockwise direction limit. This is not correct. Check to see if angles have been reversed.

RC16- The choice of using Janbu's empirical coefficient (0 or 1) was incorrectly done.

RC17- If the Janbu empirical coefficient is being used, the soil case was chosen incorrectly, i.e.. not equal to one of the following integers 1, 2, 3.

BLOCK Error Codes

BK01- The number of boxes specified for a sliding block search exceeds 10. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

BK02- The length specified for the line segments used to generate the active and passive portions of the trial failure surfaces is less than or equal to zero. The length must be greater than zero.

BK03- The two coordinate points specified to define the centerline of the box indicated have not been specified correctly. The left point must be specified first.

BK04- The box indicated and the one specified before it are not properly ordered, or they overlap. All boxes must be specified in left to right order and the boxes are not allowed to overlap one another.

BK05- The box indicated is wholly or partially defined outside of the 1st

quadrant. All problem geometry must be located within the 1st quadrant.

BK06- The box indicated is wholly or partially above the defined ground surface. Each box must be defined totally below the ground surface.

BK07- It is not possible to complete the active portion of the failure surface from part of or all of the last box specified. The last box specified must be entirely to the left of the right end of the defined ground surface.

BK08- It is not possible to complete the passive portion of the failure surface from part of or all of the first box specified. The first box specified must be entirely to the right of a fictitious line extended downward at forty-five deg with the horizontal from the left end of the defined ground surface.

BK09- The number of points defining a generated trial failure surface exceeds 100. The length specified for the line segments of the active and passive portions of the generated trial failure surfaces must be increased.

BK10- 200 attempts to generate a single trial failure surface have failed. The search limitations are either too restrictive or they actually prevent successful generation of a trial failure surface. Check and revise the search limitations or use an alternate trial surface generator.

BK11- Fewer than 10 trial failure surfaces have been specified to be generated. A minimum of 10 must be generated.

BK12- The point(s) calculated on active or passive portion of the sliding block is not within the horizontal extent of the defined ground surface. Either the specified boxes should be changed or the geometry of the problem should be extended to include the point(s) in question.

BK16- The choice of using Janbu's empirical coefficient (0 or 1) was

incorrectly done.

BK17- If the Janbu empirical coefficient is being used, the soil case was chosen incorrectly, i.e., not equal to one of the following integers 1, 2, 3.

TIES Error Codes.

TI01- An attempt has been made to suppress or reactivate undefined tieback loads. Data must be defined by a prior use of command TIES before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their use, whether the data are active or suppressed.

TI02- The number of tieback loads specified exceeds 10. The problem must either be redefined so fewer tieback loads are used, or dimensioning of the program must be increased to accommodate the problem as defined.

TI03- A negative coordinate has been specified for the tieback load indicated or the calculated Y coordinate of the end of the tieback is negative. All problem geometry must be located within the first quadrant.

TI04- The inclination limits have been exceeded for the tieback load indicated. The inclination of a tieback load must be equal to or greater than zero deg and less than 180 deg as measured clockwise from the horizontal.

TI05- The point of application of the tieback load specified does not lie on the ground surface boundary specified. Check the boundary number specified and the X and Y coordinates of the point of application of the tieback load indicated.

TI06- The horizontal spacing between tiebacks for the row row of tiebacks

indicated is incorrect. The horizontal spacing between tiebacks must be greater than or equal to 1 ft (or 1 meter if using SI units).

TI07- The length of the tieback indicated is incorrect. The length of a tieback must be greater than or equal to zero (ft). Zero is used for loads other than tieback type of loads.

SPENCR Error Code

SP01- An incorrect value for the approximate slope angle has been specified. The slope angle specified must be greater than zero (deg) and less than 90 (deg).

GRAPHICAL OUTPUT

STABL has two capacities for plotted output. The first uses plotting devices which produce high resolution plots such as Hewlett-Packard HP-7470A or HP-7475A pen plotter (Figure 19 & 20). A good representation of the problem geometry is clearly displayed. Its use provides an excellent opportunity to visually check whether data have been prepared properly. (Just because STABL accepts the data, doesn't mean they are correct). To indicate what each line segment represents, piezometric surfaces are marked with a "W" at each point defining each surface, trial surface generation limits with an "L", and surcharges with a "P", whereas soil boundaries are unmarked.
PLOTSTBL is a program written in BASIC for plotting the graphical output from PCSTABL5M using the above mentioned plotting devices. PLOTSTBL reads the plotted output file created by PCSTABL5M which contains three letter commands and coordinates for plotting by PLOTSTBL.
Information about hardware and software requirements, and running the PLOTSTBL appear in the next chapter.

Due to system operation problems, there is usually a lengthy delay in processing these plots. In order to provide immediate access to basically the same plotted information, the matrix printer and monitor are used to provide crude resolution plots utilizing print characters (Figure 21). Only the end points of boundaries and series. of points defining surfaces are plotted. Each point is assigned a particular character depending upon what point defines.

Having the knowledge of the problem geometry, the user can connect the points to make the plot more recognizable. The resolution is low; characters are spaced ten per inch along the vertical axis and six per inch along the horizontal axis. As a result, more than one point may be scaled within the same plot position. When this occur, the point with the highest priority will be represented by its print character. Print characters used by STABL and the points they represent are listed below in order of priority, highest priority first.

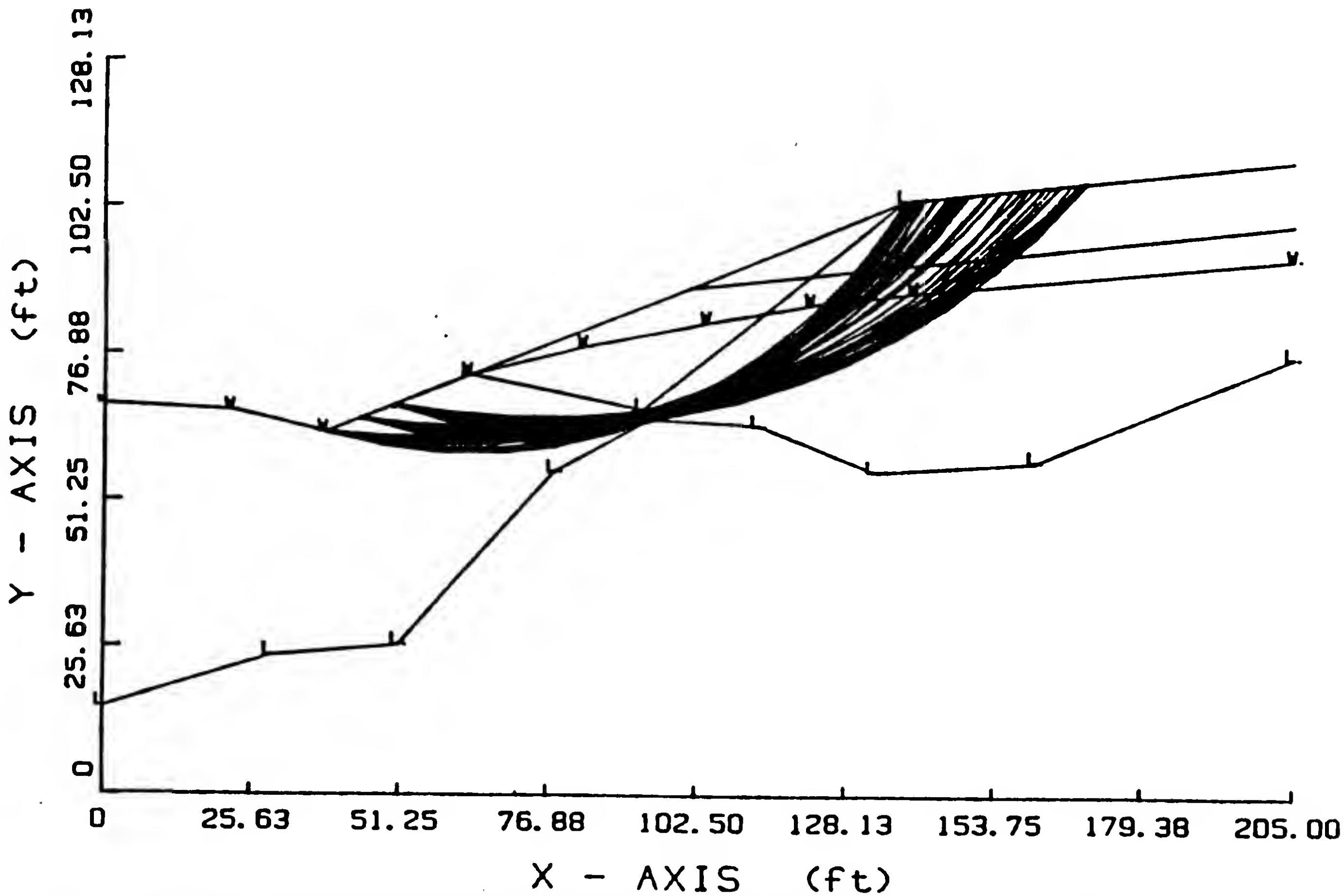


Figure 19: Example HP-7470A plot with 100 circular surfaces

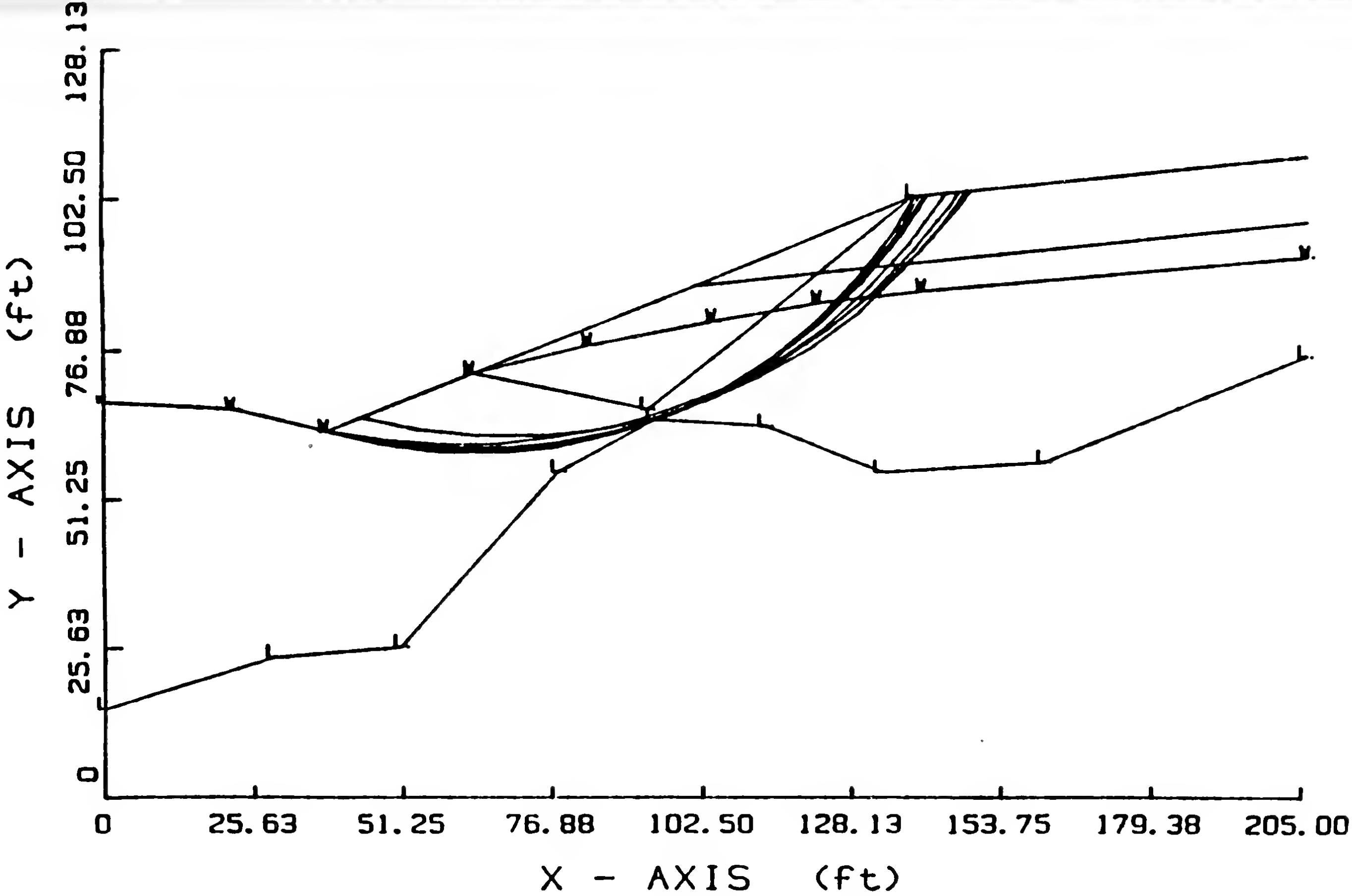
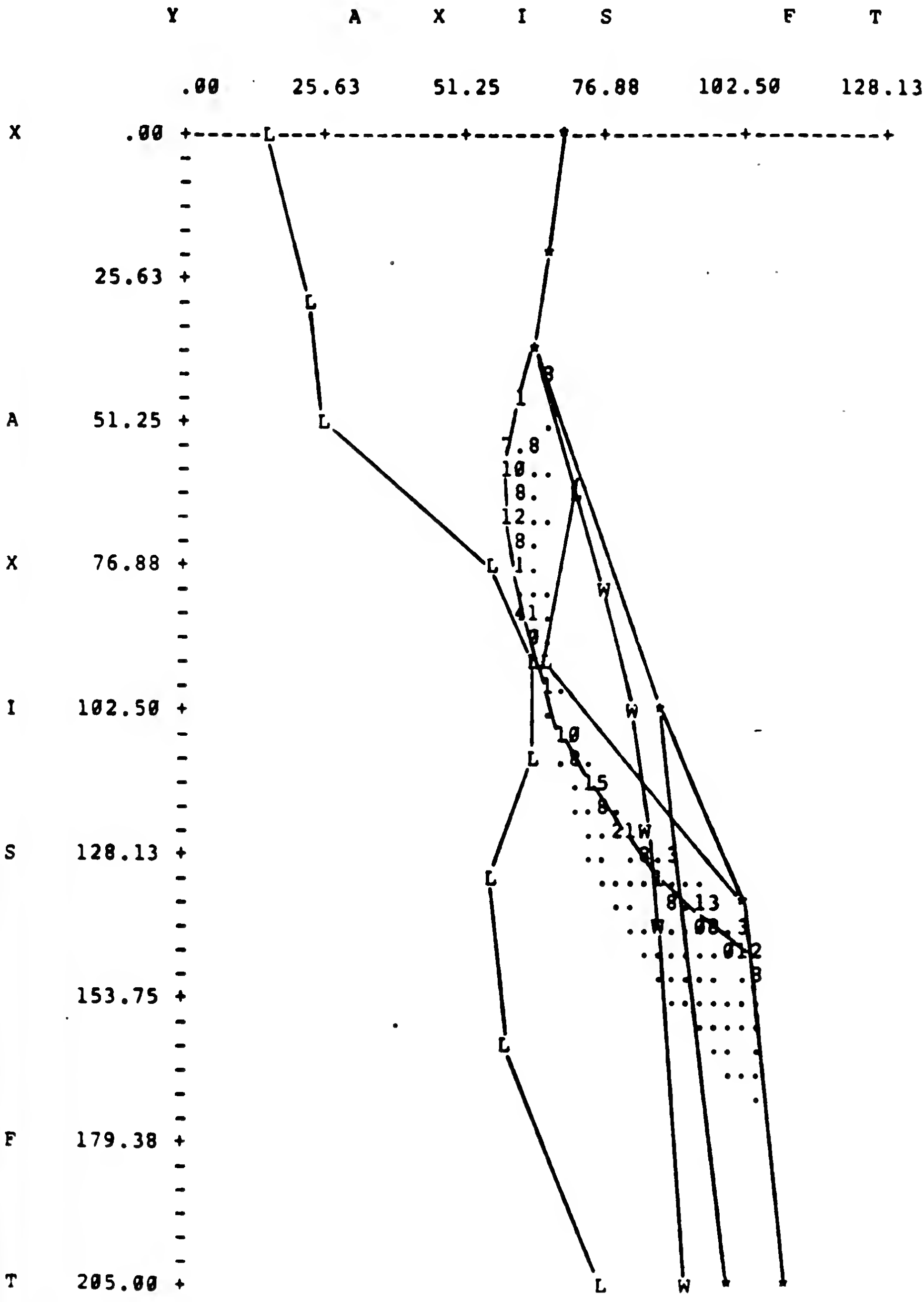


Figure 20: Ten most critical surfaces from Figure 19


Y AXIS FT
.00 25.63 51.25 76.88 102.50 128.13
X AXIS FT
.00 25.63 51.25 76.88 102.50 128.13 153.75 179.38 205.00

* end points of ground surface and subsurface profile boundaries

L end points defining surface generation boundaries

W points defining the water surface

1 points defining the most critical generated surface

2 points defining the second most critical generated surface

3 points defining the third most critical generated surface

4 points defining the fourth most critical generated surface

5 points defining the fifth most critical generated surface

6 points defining the sixth most critical generated surface

7 points defining the seventh most critical generated surface

8 points defining the eighth most critical generated surface

9 points defining the ninth most critical generated surface

0 points defining the tenth most critical generated surface

. points defining the remaining generated surface

S points defining a specified trial failure surface

T points defining location of tieback loads.

points defining the location of surcharge boundary loads

The locations of uniformly distributed surcharge boundary loads are represented with a combination of slashes and numerals. Load inclinations are not indicated on print character plots.

The plots are intended to be viewed with the printer output rotated 90 deg counterclockwise, so the left side of each print character is faced down. Viewing a plot at this orientation, the numbers above slashes represent the left ends of a corresponding surcharge boundary loads. Likewise numbers below slashes represent the right ends of corresponding surcharge boundary loads (Figure 21).

If the extent of surcharge load is narrow, both the left and right end may appear within the same horizontal print position. The number of that surcharge boundary load then appears both above and below a single slash. Occasionally, when the surcharge boundary loads of narrow extent are located adjacent to other loads, some load numbers may be absent.

Printed character plots are also useful for checking input data, although not as conveniently as the first form mentioned. When using surface generation routines, both plots serve well as visual aids for modifying search parameters for subsequent searches.

INTRODUCTION TO PCSTABL5M

A. PCSTABL5M VERSIONS

Two versions of PCSTABL5M are available for IBM compatible microcomputers.

Version 1.87 runs on any IBM compatible machine with the optional Intel 8087 Math Co-Processor. The program requires the Intel 8087 Math Co-Processor and will not run on IBM compatible machines without the 8087 math coprocessor. Version 1.87 has been compiled to utilize the Intel 8087 Math Co-Processor during execution which significantly enhances execution time.

Version 1.88 is supplied for those users who do not have the Intel 8087 Math Co-Processor. This version will run on any IBM compatible machine, however it is significantly slower than version 1.87 since it does not utilize the Intel 8087 Math Co-Processor. Version 1.88 will run in a machine with or without coprocessor, however performance on a machine with an 8087 coprocessor will be the same as that on a machine without an 8087 coprocessor.

For faster execution on machines without the 8087 math coprocessor, the 1.88 version has been compiled using an alternate math library which sacrifices a small amount of precision in return for faster execution. The amount of error is very small and is not significant for engineering purposes, however results will vary somewhat from the 1.87 version.

Version 1.87 is strongly recommended since it will run 3 to 5 times faster than version 1.88 and does not sacrifice any accuracy. For example, a moderately complex problem which generates and analyzes 100 failure surfaces using the Simplified Bishop method of slices takes approximately 4 minutes to run using the 8087 version (version 1.87), while the same problem takes approximately 12 minutes to run using the non-8087 version (version 1.88).

B. Comparison of PCSTABL5M to STABL5M.

PCSTABL5M is a microcomputer version of the mainframe STABL5M program. PCSTABL5M contains all the options and capabilities of STABL5M including:

-Simplified Janbu, Simplified Bishop, and Spencer's method of slices.

-Isotropic and anisotropic soil parameters.

-Piezometric water surfaces

-Specific surface or random search surface generation.

-Circular, random or block potential failure surfaces.

-Tieback, surcharge and earthquake loads.

The only notable difference between PCSTABL5M and STABL5M is that the random number generator from STABL3 has been used in STABL5M, since the number generator used in STABL5M is not compatible with the IBM microcomputer. Therefore, slight differences may be noticed in the failure surfaces generated and the factors of safety calculated, when comparing the results obtained from PCSTABL5M and STABL5M.

C. Hardware and Software Requirements.

The following is a list of the minimum hardware requirements for operating PCSTABL5M.

1. One IBM-XT or IBM compatible microcomputer with 256 kb of memory.
2. One double-sided, double density disk drive.
3. Dot matrix printer (11" or 17" wide carriage).
4. One 80 column monochrome display.

5. Optional: Hewlett-Packard 7475A six pen plotter.

6. Optional: One Intel 8087 Math Co-Processor.

PCSTABL5M will run on machines using any IBM or MS-DOS disk operating system (DOS), including DOS versions 1.0 to 3.0. Software requirements for using PCSTABL5M include:

1. A line editor or word processor for creating input files.

2. A BASIC interpreter (IBM-BASIC or GW-BASIC: Only required if using optional plotting routine, PLOTSTBL).

Color monitors, hard disk drives, other types of printers, additional memory space and the like, may enhance the efficiency of PCSTABL5M, but are not required.

D. Diskette Contents

PCSTABL5M is supplied on two 5 1/4 inch double-sided, double-density, floppy diskettes, and one single-sided, double-density, floppy diskette. The contents of these diskettes are listed below:

DISK # 1

PCSTABL5M.EXE	Executable Program
EXAMPLE1.IN	Example Input Files
EXAMPLE2.IN	
EXAMPLE1.OUT	Example Output Files
EXAMPLE2.OUT	
EXAMPLE1.PLT	Example Plot Files
PLOTSTBL.BAS	BASIC Plotting Program

DISK = 2

587READ1.FOR
587READ2.FOR
587STABL.FOR FORTRAN Source Code
587SURF.FOR
FSPENC.FOR
587PLOT.FOR
587MISC.FOR

DISK = 3

587FACT.FOR FORTRAN Source Code
587RAND.FOR

The FORTRAN source code of PCSTABL5M has been divided into the nine files listed above. The source code is for 1.87 version (with the Math Co-Processor). These files were compiled and linked together into the executable program PCSTABL5M.EXE using the Microsoft FORTRAN compiler, version 3.2. The Microsoft compiler however is not required for running the program, and is only required if the user makes changes in the program. Note that only DISK #1 is required to run PCSTABL5M.

It is strongly recommended that the user create backup copies of the original diskettes supplied, and use these copies for day-to-day use, while saving the original diskettes for permanent storage.

E. Creation of Input Files

Input files for PCSTABL5M utilize free-format data entry, as used by other versions of STABL. Input files may be created using a line editor, text editor, or a

word processor. Since word processors generally store format characters along with the text, input files must be saved without formatting so that format characters will not be encountered when running the program. If such characters are encountered, execution errors will result.

Refer to preceding pages for proper formatting of input data.

F. Running PCSTABL5M

Operation of PCSTABL5M is very simple. After creating an input file and storing it on a diskette, simply type "PCSTABL5M" in either uppercase or lowercase letters followed by a return. The program will be loaded into memory and will prompt the user for the current date, time, name of the user, input filename, output filename, and filename for subsequent plotting of output. The date, time, and name of the user may be in any form desired. Note that the input and output files do not need to be on the same diskette or disk drive with PCSTABL5M, as supplied on disk #1. Disk drive specifications may be used when invoking PCSTABL5M (i.e., B:PCSTABL5M), or when specifying input and output files (i.e., A:EXAMPLE1.OUT). In addition, if an invalid or nonexistent input filename is specified, the operating system will display an error message to the screen and return the user to the DOS prompt.

Filenames for the output file and the plotted output file may be any legal DOS filename. Note that an existing output file on a diskette will be overwritten if an existing output filename is reused. To avoid overwritting existing files, use unique names for each output. All responses to prompts may be uppercase or lowercase characters, including numbers and legal DOS filename symbols.

The program will write the output to the screen and the disk simultaneously. This includes the input parameters, method of analysis, and results. When running a problem which analyzes many surfaces, no output will be written to the screen while trial surfaces are being generated and analyzed. After all surfaces have been generated and analyzed, and the ten most critical factors of safety

sorted, the program will resume displaying the results to the screen.

If a plotted output file is specified, the program will write commands and sets of coordinates to the disk for subsequent plotting by the PLOTSTBL.BAS program on a Hewlett-Packard plotter. If a plotted output file is not desired, simply type "None" when prompted for the plotted output filename. To save diskette space, only specify a plotted output file for those runs whose outputs will be plotted using PLOTSTBL. Note that plotting is not performed during execution of PCSTABL5M. This allows the user to examine the results, and plot those only results which are desired.

G. Plotting routine for PCSTABL5M. (PLOTSTBL)

G1. Hardware and Software Requirements.

The only hardware required for plotting graphical output is a Hewlett-Packard HP-7470A or HP-7475A pen plotter.
PLOTSTBL is written such that the plotter must be configured at a baud rate of 9600 and connected to serial communication port #1 on the microcomputer. If the user desires to connect the plotter to serial communication port #2, the user must modify line 710 of the PLOTSTBL program to read "com2" instead of "com1". Likewise, if the user desires to use a baud rate other than 9600, the user must replace the "9600" in line 710 of PLOTSTBL with the desired baud rate. For further information on interfacing an HP plotter with the user's specific microcomputer, the user should consult his or her own plotter and microcomputer manuals.

The only software required to run PLOTSTBL is a BASIC interpreter (IBM-BASIC or GW-BASIC), which is normally supplied along with the disk operating system upon purchase of an IBM compatible microcomputer.

G2. Running PLOTSTBL

To run PLOTSTBL, invoke the BASIC interpreter by typing "BASICA", load the PLOTSTBL program by hitting the "F3" (LOAD) key and type "PLOTSTBL". To begin plotting, hit the "F2" (RUN) key and answer the prompts.

The program will prompt the user for the name of the input file to be used for plotting, the first line of the plot title, the second line of the plot title, a request for pen changes, and units for labeling the plot. If pen changes are specified, the program will ask the user if a two or six pen plotter is being used. As with PCSTABL5M, disk drive specifications may be used when invoking PLOTSTBL or specifying the input file. The file to be used for plotting must be an existing file or diskette. If the input file specified for plotting is nonexistent, the interpreter will display the error message, "File not found". The user must then hit the "F2" key to restart PLOTSTBL. The title of the plot may contain uppercase and lowercase letters, numbers and symbols, and will appear at the top of the plot.

The user may enhance the plot by specifying that the program prompt the user for pen changes during plotting. This allows the user various colors and pen thicknesses during plotting. PLOTSTBL is written so that the user may use any number of pens during plotting and the user is not restricted to the number of pens available on the plotter being used. The program will stop during execution, return the pen to its holder, and prompt the user for a pen change for a particular set of line segments (i.e., boundaries, water surfaces, etc.). The user then specifies the desired pen, and if necessary, replaces the desired pen in the user specified pen holder, and the program continues plotting. The user may also specify that no pen changes are desired. In this case, only pen #1 will be used for the entire plot.

For convenience, an option for specifying the units of the plot is provided. The user may specify that the plot be labeled in either "Feet" or "Meters". Note that specifying either unit does not alter the plot, only the label on the axes of the plot.

For outputs where more than ten surfaces have been generated, two plots will be produced. The first plot will contain all the surfaces generated, while the second plot will contain only the ten most critical surfaces. The user will be prompted to change the paper and place the desired pen for the axes of the plot in pen holder #1. The most critical failure surface plotted will be noted by asterisks (*).

REFERENCES

1. Boutrup, Eva 1977, "Computerized Slope Stability Analysis for Indiana Highways", Joint Highway Research Project No. 77-25 and 77-26 (volumes), School of Civil Engineering, Purdue University, W. Lafayette, Indiana, Dec., 512 pp.

2. Boutrup, E. and Lovell, C. W. (1978), "Searching Techniques in Slope Stability Analysis" (Extended Abstract). Proceedings, 15th Annual Meeting of the Society of Engineering of Engineering Science, Gainesville, Florida. Dec., pp. 447-452.

3. Boutrup, E., Lovell, C. W. and Siegel, R. A. (1979), "STABL2....A Computer Program for General Slope Stability Analysis", Proceedings, 3rd International Conference on Numerical Methods in Geomechanics, Aachen, W. Germany, pp. 747-757

4. Boutrup, E. and Lovell, C. W. (1980), "Searching Techniques in Slope Stability Analysis", Engineering Geology, Vol. 16, No. 1/2, July. Special Issue on Mechanics of Landslide and Slope Stability, pp. 51-61.

5. Carpenter, J.R. (1985), "STABL5....The Spencer Method of Slices: Final Report", Joint Highway Research Project No. JHRP-85-17, School of Civil Engineering, Purdue University, West Lafayette, Indiana, August, 1985.

6. Carpenter, J.R. (1986), "Slope Stability Analysis Considering Tiebacks and Other Concentrated Loads", Joint Highway Research Project No. JHRP-86-21, School of Civil Engineering, Purdue University, West Lafayette, Indiana. Indiana, 1986.

7. Carter, R. K. (1971), "Computer Oriented Slope Stability Analysis by Method of Slices", Thesis, MSCE Purdue University, West Lafayette, Indiana, Jan.,120 pp.

8. Chen, R-H (1981), "Three-Dimensional Slope Stability Analysis", Joint Highway Research Project No. 81-17, School of Civil Engineering, Purdue University, West Lafayette, Indiana, Dec., 298 pp.

9. Lovell, C. W. (1982) "Three-Dimensional Slope Stability", Thirteenth Annual Ohio River Valley Soils Seminar, Lexington, Kentucky, Oct., 9 pp.

10. Rooney, M. F., Howland, J. D. and Molz, R. J. (1982), "Implementing Large Programs on Microcomputers", Journal, Technical Councils of ASCE, Vol. 108, No. TCI, May, pp. 125-137.

11. Siegel, R. A. (1975a), "Computer Analysis of General Slope Stability Problems", Joint Highway Research Project No. 75-8, School of Civil Engineering, Purdue University, West Lafayette, Indiana, May, 210 pp.

12. Siegel. R. A. (1975b). "STABL User Manual", Joint Highway Research Project No. 75-9, School of Civil Engineering. Purdue University, West Lafayette, Indiana. May, 104 pp. (Revised by E. Boutrup, June 1978).

13. Siegel, R. A., Kovacs, W. D. and Lovell, C. W. (1978), "New Method for Shear Surface Generation for Stability Analysis", Proceedings. 29th Annual Highway Geology Symposium, Annapolis, Maryland. May, pp. 295-312.

14. Siegel, R. A., Kovacs, W. D. and Lovell, C. W. (1981), "Random Surface Generation in Stability Analysis", Journal, Geotechnical Engineering Division, ASCE, July, pp. 996-1002.

15. Taylor, D.W. (1948), "Fundamentals of Soil Mechanics", Wiley & Sons, New York, pp. 455-462.

16. Tenier, P. and Morlier, P. (1982), "Influence of Concentrated Loads on Slope Stability", Canadian Geotechnical Journal, Vol. 19, Feb., pp. 396-400.

17. Verduin, J. R. (1987), "PC STABL5M DESCRIPTION OF MODIFICATIONS", Internal Report in Ground Engineering No 141, School of Civil Engineering, Purdue University, West Lafayette, Indiana, August.

APPENDIX A

EXAMPLE PROBLEM

A. DESCRIPTION OF PROBLEM

This example concerns the long term stability of a cut in a soft clay material (Figure A1). Without worrying about the validity of such a problem let it be defined as follows for illustration.

A ground water table is present at a depth of about 17 feet below the existing ground surface which gently slopes toward the cut. An irregular bedrock surface lies at a relatively shallow depth. The variation of the bedrock surface normal to the plane of the profile is insignificant. Therefore a two-dimensional analysis is assumed appropriate.

The shear parameters ($c' = 500$ psf, $\phi' = 14$ deg.) do not vary significantly with depth, but due to desiccation, tension cracks are assumed to extend to a depth of approximately 11 feet.

By defining the problem geometry with straight lines (Figure A2), the problem can be handled by STABL. The total number of boundaries defined by command PROFIL is six, of which five define the ground surface. A subsurface boundary is used to differentiate a zone containing tension cracks from the remaining clay material. The boundaries are ordered ground surface boundaries first, left to right, with the single subsurface boundary last, satisfying program requirements. The 4th and 5th boundaries on the ground surface are above the tension crack zone, so they are assigned a different soil type number from that assigned to the other boundaries. The clay below the tension zone has been arbitrarily assigned soil type number 1 and that within the tension zone, soil type number 2.

The bedrock has been assumed competent, with no possibility of failure within it. Therefore, surface generation boundaries, defined by command LIMITS, are used to approximate the bedrock surface. Generation of trial failure surfaces which pass through the bedrock is thus prevented.

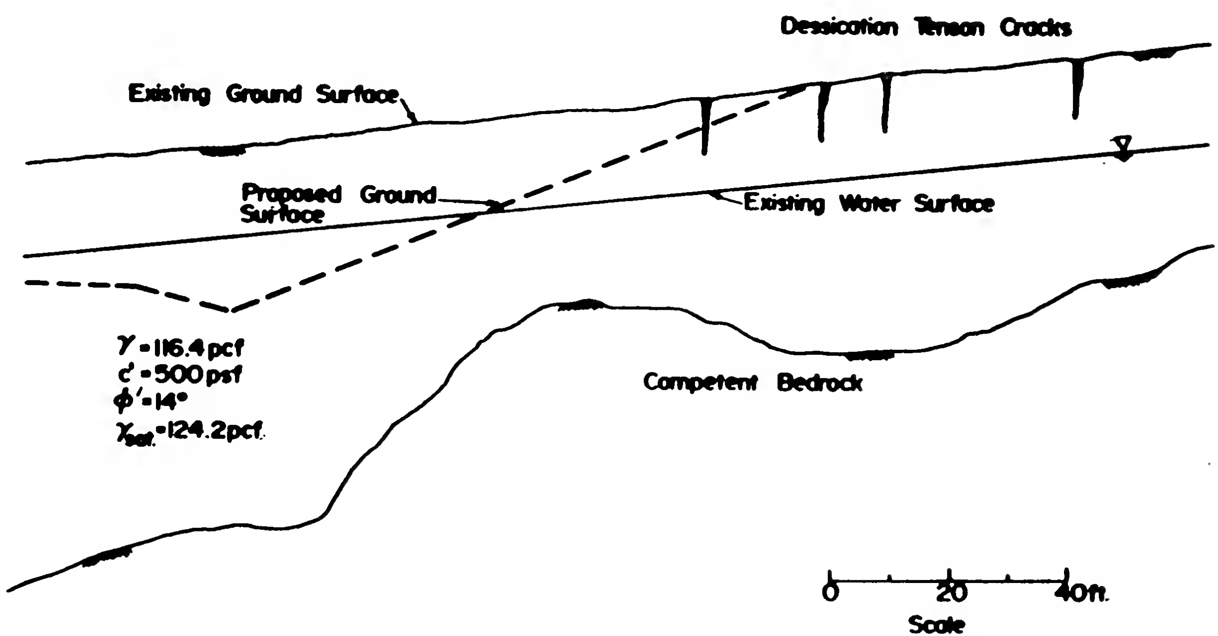


Figure A1: Geometry of example problem

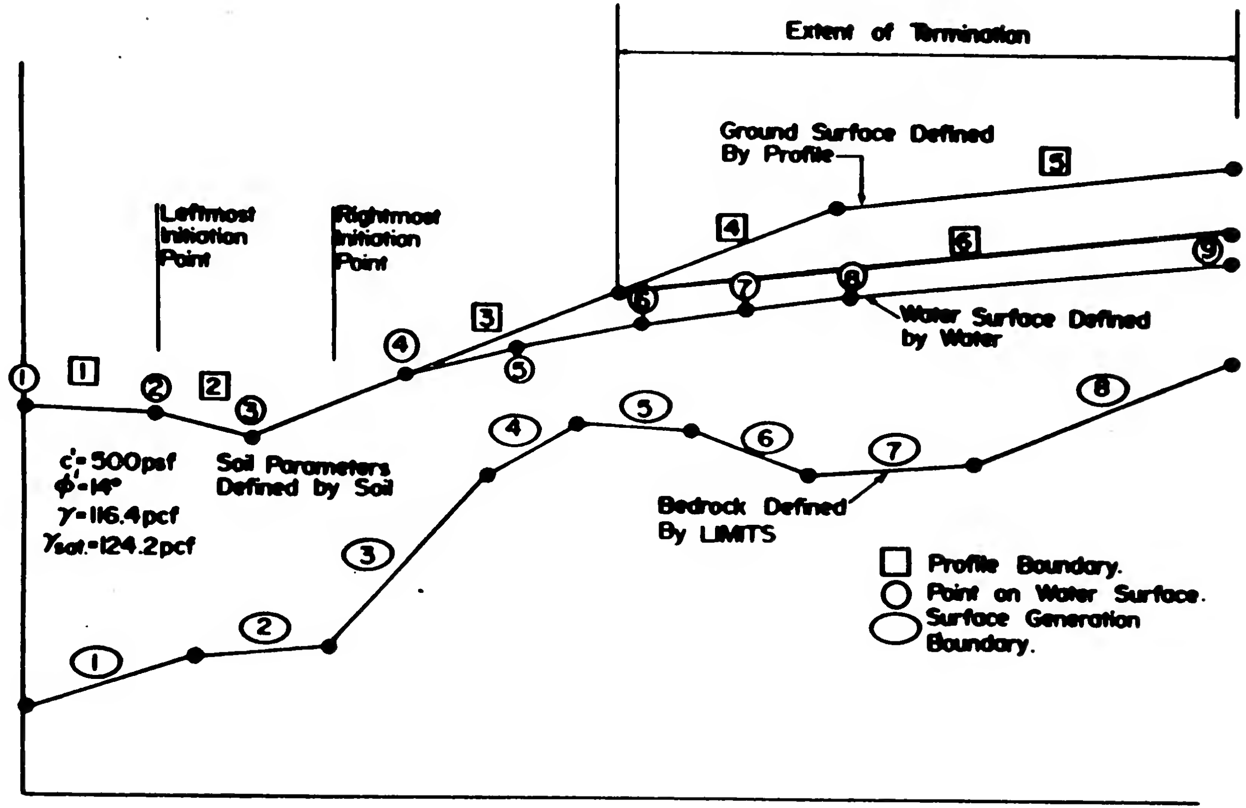


Figure A2: Linear approximation of example problem geometry.

It would also have been possible to define the bedrock surface with additional subsurface boundaries defined by command PROFIL. A third soil type with appropriate strength parameters would have been then assigned. The factor of safety of surfaces generated through the bedrock would have been obviously much higher than those above it. The alternative would have been wasteful, and therefore has not been used for this example. However it could have been applicable if the bedrock material was weak.

Of the eight surface generation boundaries which are specified, all eight will deflect generating surfaces upward. The boundaries are therefore not required to be specified in any specific order. However, to maintain consistency, they have been specified in continuous order from left to right.

The water surface is defined by eight points, of which the first four lie at the ground surface. The remaining points have been adjusted to account for response of the ground water table to the change in boundary conditions introduced by the cut.

The two soil types assigned to the boundaries defined by command PROFIL are defined by command SOIL in order of soil type number. Soil type 1 has shear strength parameters of $c' = 500$ psf and $\phi' = 14$ deg. Soil type 2, since it is in tension, is assigned zero shear strength parameters. The moist unit weight of both soil types is 116.4 pcf. The saturated unit weight of soil type 1 is 124.2 pcf, and that of soil type 2 has arbitrarily been assigned 116.4 pcf. The saturated unit weight of soil type 2 will not be used in the analysis however, as soil type 2 is entirely above the water surface. The pore pressure constant and pore pressure parameter for both soil types are not used in this example, so they are assigned zero values. The piezometric surface number is 1 for both soil types.

The Janbu simplified method will be used. Searching for the critical surface will be carried out using each of the three trial failure surface generators. Normally, only one generator, or a combination of two, would be used for most problems, but it is instructive to demonstrate the use of each for the same problem. Results of the same problem, using Bishop and Spencer methods, appear in Table A1.

B. CREATING AND RUNNING THE PROGRAM

(a) USE OF CIRCULAR TYPE GENERATOR (CIRCLE)

It is doubtful that a failure surface would initiate beyond the toe of the slope, because of the controlling influence of the bedrock surface. Since the search is restricted to circular shaped surfaces, the influence of the bedrock may, in fact, force the critical surface to pass through a point on the face of the slope, rather than at the toe of the slope or beyond.

Since the Janbu method is used it was decided to use the Janbu coefficient (there is also the option not to use it) for the case of c', and ϕ' larger than zero.

Somewhat arbitrarily, it is decided to generate a total of one hundred surfaces; ten surfaces from each of ten initiation points. The leftmost initiation point is positioned at the toe of the slope, X = 38 ft, and the rightmost on the face of the slope at X = 70 ft.

The termination limits are also somewhat arbitrarily selected. Usually, the critical surface of a slope will pass a short distance behind the crest of a slope. However, the bedrock may force the critical surface to be located short of the crest. The left termination limit is set at X = 120 ft to allow for this possibility. The right termination limit is set at X = 180 ft. If later, the ten most critical surfaces are found to congregate at either limit, the termination limits can be revised for subsequent runs.

The depth limitation is not required, because the bedrock surface, as defined by surface generation boundaries, prevents the generation of deep failure surfaces. It must be specified, however, and for this example, it is set at Y = 0.

The length of the line segments defining the circular shaped surfaces is set at ten feet. This is one-fourth of the height of the slope. Lengths one-fourth to one-third the height of the slope are generally reasonable. The length specified for the

line segments has a direct influence on computation time. Although short line segments define circular surfaces more accurately, they require more computation time for surface generation and the factor of safety calculation.

No restrictions are placed upon the angle of inclination of the initial line segment. Therefore both the clockwise and counterclockwise inclination limits are specified as zero.

A listing of the raw input data, is shown on the next page in exla.in, as it would be prepared for the problem as described. Note that all the data begin in the first column; the commands are on individual lines; the data items on each line are separated by single blank spaces ; and real and integer numeric data, respectively, do and do not contain decimal points.

Following the listing of the raw input data is the output for the commands executed for the first run. The last information printed is the print character plot of the problem (Figure A3) resulting from the use of the command CIRCLE. Two additional plots, prepared by an HP-7475A six-pen plotter are also included (Figure A4 & A5). All the input data, associated with each command used, are displayed with the output. The coordinates of the ten most critical surfaces along with their respective factors of safety are printed when search commands are used.

The print character plot contains information regarding the input data and the surfaces generated. The line segments connecting points can be sketched in for clearer interpretation. The ten most critical of the surfaces generated appear as strings of one digit numbers, while the remaining surfaces generated appear as dots.

From this plot the ten most critical surfaces are found to be located within the extent of all the surfaces generated. This indicates a fairly good choice of initial restraints used to generate the surfaces.

The two HP-7475A plots show basically the same information as the print character plot, but in a form more easily interpreted. The first of these plots shows the extent of the surfaces generated, while the second displays the ten

```
PROFIL
EX1A.IN (Janbu Method-First Trial-CIRCLE Gen.)
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0. 1
116.4 116.4 0. 0. 0. 0. 1
WATER
1 0.
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
8 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
CIRCLE
1 2
10 10
38. 70. 120. 180.
0. 10. 0. 0.
```

** PCSTABL5M **

by
Purdue University

1

--Slope Stability Analysis--
Simplified Janbu, Simplified Bishop
or Spencer`s Method of Slices

Run Date:	10/9/88
Time of Run:	3:00 pm
Run By:	E. Achilleos
Input Data Filename:	exla.in
Output Filename:	exla.out

PROBLEM DESCRIPTION EX1A.IN (Janbu Method-First Trial-CIRCLE Gen.)

BOUNDARY COORDINATES

5 Top Boundaries
6 Total Boundaries

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Soil Type Below Bnd
1	.00	68.00	22.00	67.00	1
2	22.00	67.00	38.00	63.00	1
3	38.00	63.00	101.00	88.00	1
4	101.00	88.00	138.00	103.00	2
5	138.00	103.00	205.00	110.00	2
6	101.00	88.00	205.00	99.00	1

1

ISOTROPIC SOIL PARAMETERS

2 Type(s) of Soil

Soil Type No.	Total Unit Wt. (pcf)	Saturated Unit Wt. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Param.	Pressure Constant (psf)	Piez. Surface No.
1	116.4	124.2	500.0	14.0	.00	.0	1
2	116.4	116.4	.0	.0	.00	.0	1

1

1 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

Unit Weight of Water = 62.40

Piezometric Surface No. 1 Specified by 9 Coordinate Points

Point No.	X-Water (ft)	Y-Water (ft)
1	.00	68.00
2	22.00	67.00
3	38.00	63.00
4	63.00	73.00
5	83.00	78.00
6	104.00	82.00
7	122.00	85.00
8	140.00	87.00
9	205.00	93.00

Searching Routine Will Be Limited To An Area Defined By 8 Boundaries Of Which The First 8 Boundaries Will Deflect Surfaces Upward

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)
1	.00	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Circular Surfaces, Has Been Specified.

Janbus Empirical Coef. is being used for the case of c & phi both > 0
100 Trial Surfaces Have Been Generated.

10 Surfaces Initiate From Each Of 10 Points Equally Spaced
Along The Ground Surface Between X = 38.00 ft.
and X = 70.00 ft.

Each Surface Terminates Between X = 120.00 ft.
and X = 180.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation At Which A Surface Extends Is Y = .00 ft.

10.00 ft. Line Segments Define Each Trial Failure Surface.

Following Are Displayed The Ten Most Critical Of The Trial Failure Surfaces Examined. They Are Ordered - Most Critical First.

* * Safety Factors Are Calculated By The Modified Janbu Method * *

Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	41.56	64.41
2	51.43	62.82
3	61.40	62.11
4	71.40	62.29
5	81.35	63.34
6	91.16	65.27
7	100.76	68.05
8	110.09	71.67
9	119.05	76.10
10	127.59	81.30
11	135.64	87.24
12	143.13	93.86
13	150.01	101.12
14	152.73	104.54

*** 1.371 ***

Individual data on the 21 slices

Slice No.	Width Ft(m)	Weight Lbs(kg)	Water Force Top Lbs(kg)	Water Force Bot Lbs(kg)	Tie Force Norm Lbs(kg)	Tie Force Tan Lbs(kg)	Earthquake Force Hor Lbs(kg)	Earthquake Force Ver Lbs(kg)	Surchar Loa Lbs(
1	9.9	3362.4	.0	1614.7	.0	.0	.0	.0	
2	10.0	9673.2	.0	4587.9	.0	.0	.0	.0	
3	1.6	2068.2	.0	978.5	.0	.0	.0	.0	
4	8.4	12854.5	.0	6024.0	.0	.0	.0	.0	
5	9.9	18860.2	.0	8194.0	.0	.0	.0	.0	
6	1.7	3454.7	.0	1457.9	.0	.0	.0	.0	
7	8.2	17999.6	.0	7295.3	.0	.0	.0	.0	
8	9.6	22638.2	.0	8465.7	.0	.0	.0	.0	
9	.2	569.2	.0	206.5	.0	.0	.0	.0	
10	3.0	7241.1	.0	2562.6	.0	.0	.0	.0	
11	6.1	14700.4	.0	4828.8	.0	.0	.0	.0	
12	9.0	21149.9	.0	6077.9	.0	.0	.0	.0	
13	2.9	6668.0	.0	1648.0	.0	.0	.0	.0	
14	5.6	11993.3	.0	2318.5	.0	.0	.0	.0	
15	6.9	13218.9	.0	1146.5	.0	.0	.0	.0	
16	1.2	2016.9	.0	.0	.0	.0	.0	.0	
17	2.4	3911.5	.0	.0	.0	.0	.0	.0	
18	3.3	4795.3	.0	.0	.0	.0	.0	.0	
19	1.8	2181.3	.0	.0	.0	.0	.0	.0	
20	6.9	5130.7	.0	.0	.0	.0	.0	.0	
21	2.7	495.4	.0	.0	.0	.0	.0	.0	

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)

1	38.00	63.00
2	47.77	60.88
3	57.72	59.84
4	67.72	59.89
5	77.65	61.04
6	87.40	63.27
7	96.85	66.55
8	105.88	70.84
9	114.38	76.10
10	122.26	82.26
11	129.42	89.24
12	135.77	96.96
13	139.84	103.19

*** 1.372 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	52.22	68.64
2	61.90	66.12
3	71.79	64.66
4	81.78	64.28
5	91.76	64.98
6	101.60	66.77
7	111.19	69.61
8	120.41	73.47
9	129.16	78.32
10	137.33	84.08
11	144.83	90.70
12	151.56	98.09
13	156.56	104.94

*** 1.392 ***

Failure Surface Specified By 12 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	45.11	65.82
2	54.83	63.45
3	64.76	62.30
4	74.76	62.37
5	84.67	63.68
6	94.35	66.20
7	103.64	69.89
8	112.41	74.70
9	120.52	80.55
10	127.85	87.35
11	134.28	95.01
12	139.57	103.16

*** 1.419 ***

1

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	59.33	71.47
2	68.78	68.18
3	78.56	66.08
4	88.52	65.19
5	98.51	65.53
6	108.39	67.10
7	118.00	69.87
8	127.19	73.79
9	135.84	78.81
10	143.81	84.86
11	150.97	91.84
12	157.22	99.64
13	160.76	105.38

*** 1.433 ***

Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	48.67	67.23
2	58.55	65.72
3	68.53	65.02
4	78.53	65.14
5	88.48	66.08
6	98.33	67.84
7	107.99	70.39
8	117.42	73.74
9	126.54	77.84
10	135.29	82.68
11	143.61	88.22
12	151.45	94.43
13	158.76	101.26
14	162.68	105.58

*** 1.435 ***

1

Failure Surface Specified By 12 Coordinate Points

Point X-Surf Y-Surf

No.	(ft)	(ft)
1	52.22	68.64
2	61.79	65.74
3	71.67	64.22
4	81.67	64.12
5	91.59	65.44
6	101.21	68.16
7	110.35	72.22
8	118.82	77.53
9	126.45	83.99
10	133.09	91.48
11	138.59	99.82
12	140.20	103.23

*** 1.437 ***

Failure Surface Specified By 14 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	48.67	67.23
2	58.55	65.73
3	68.53	65.00
4	78.53	65.05
5	88.49	65.88
6	98.36	67.49
7	108.08	69.86
8	117.58	72.98
9	126.80	76.84
10	135.70	81.40
11	144.21	86.65
12	152.29	92.55
13	159.88	99.05
14	166.82	106.01

*** 1.440 ***

Failure Surface Specified By 13 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	62.89	72.88
2	72.11	69.01
3	81.78	66.44
4	91.70	65.21
5	101.70	65.34
6	111.59	66.83
7	121.18	69.66
8	130.29	73.77
9	138.77	79.08
10	146.44	85.50
11	153.16	92.90

12	158.81	101.15
13	160.93	105.40

*** 1.456 ***

Failure Surface Specified By 11 Coordinate Points

Point No.	X-Surf (ft)	Y-Surf (ft)
1	62.89	72.88
2	71.99	68.74
3	81.68	66.25
4	91.65	65.50
5	101.60	66.50
6	111.22	69.22
7	120.22	73.57
8	128.32	79.44
9	135.28	86.63
10	140.87	94.92
11	144.77	103.71

*** 1.457 ***

PRINT CHARACTER PLOT FOR FIRST TRIAL

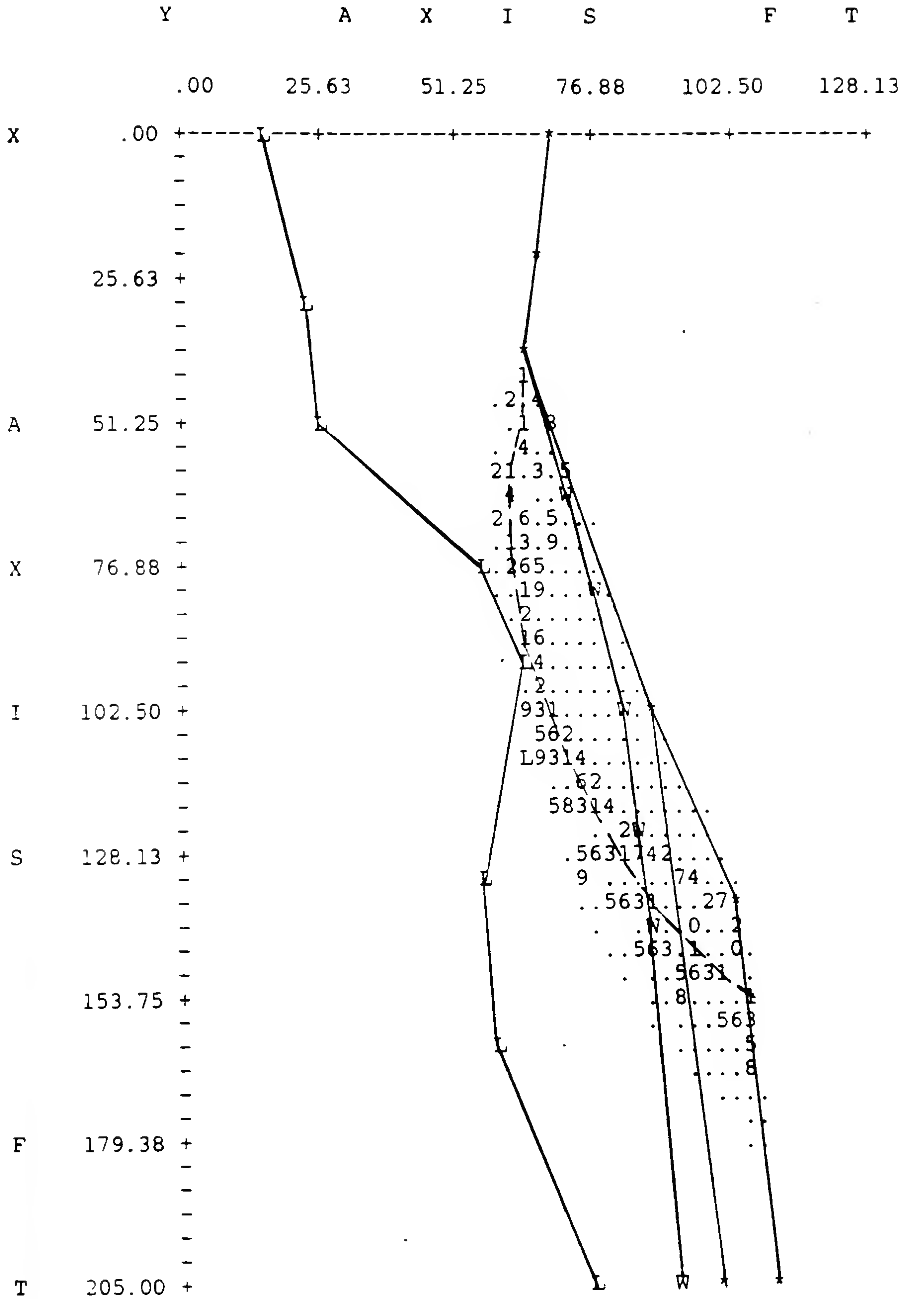
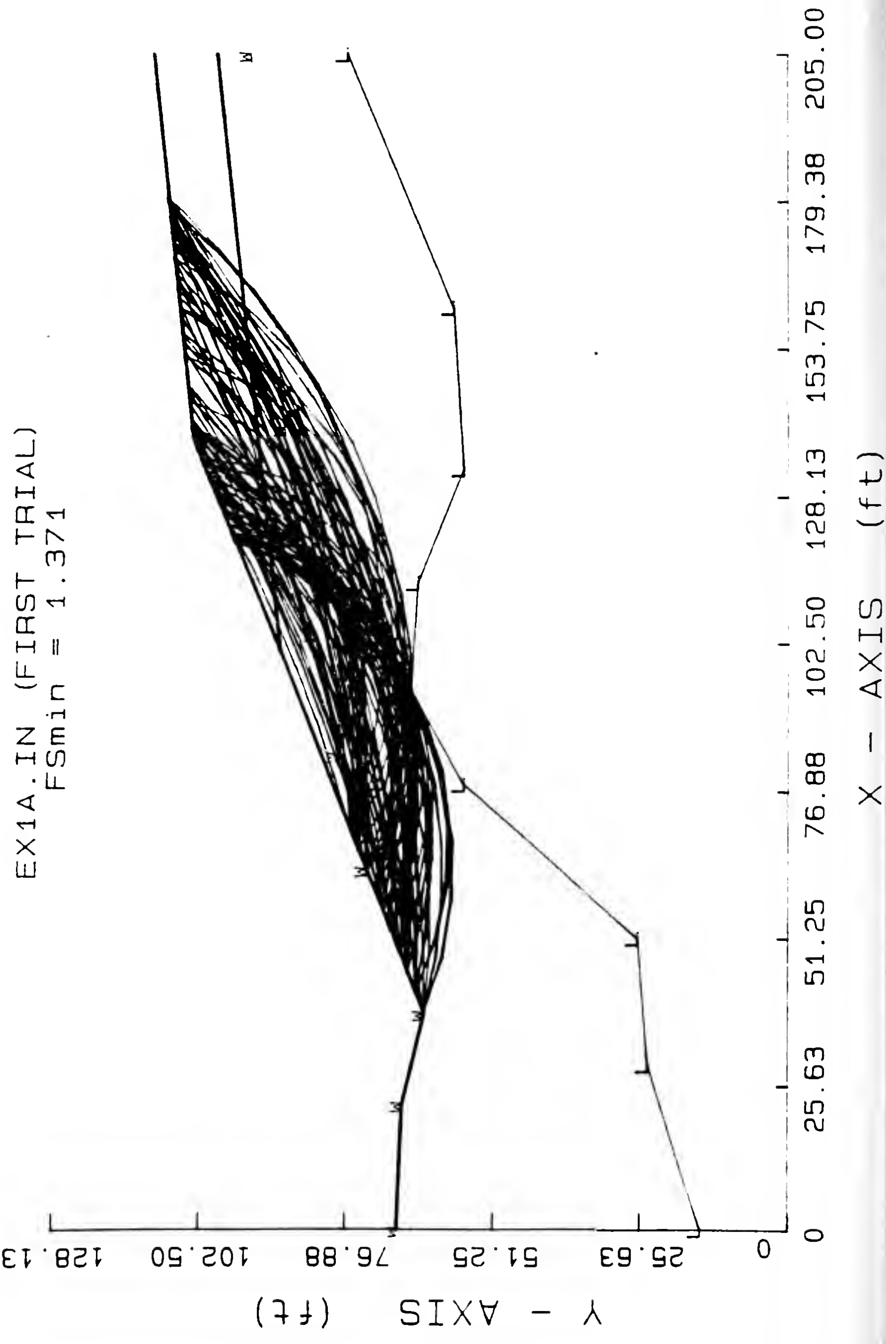


Figure A3: Print character plot for first trial.



EX1A.IN (FIRST TRIAL)
FSmin = 1.371
0
25.63
51.25
76.88
102.50
128.13
153.75
179.38
205.00
X - AXIS (ft)
0
25.63
51.25
76.88
102.50
128.13
Y - AXIS (ft)

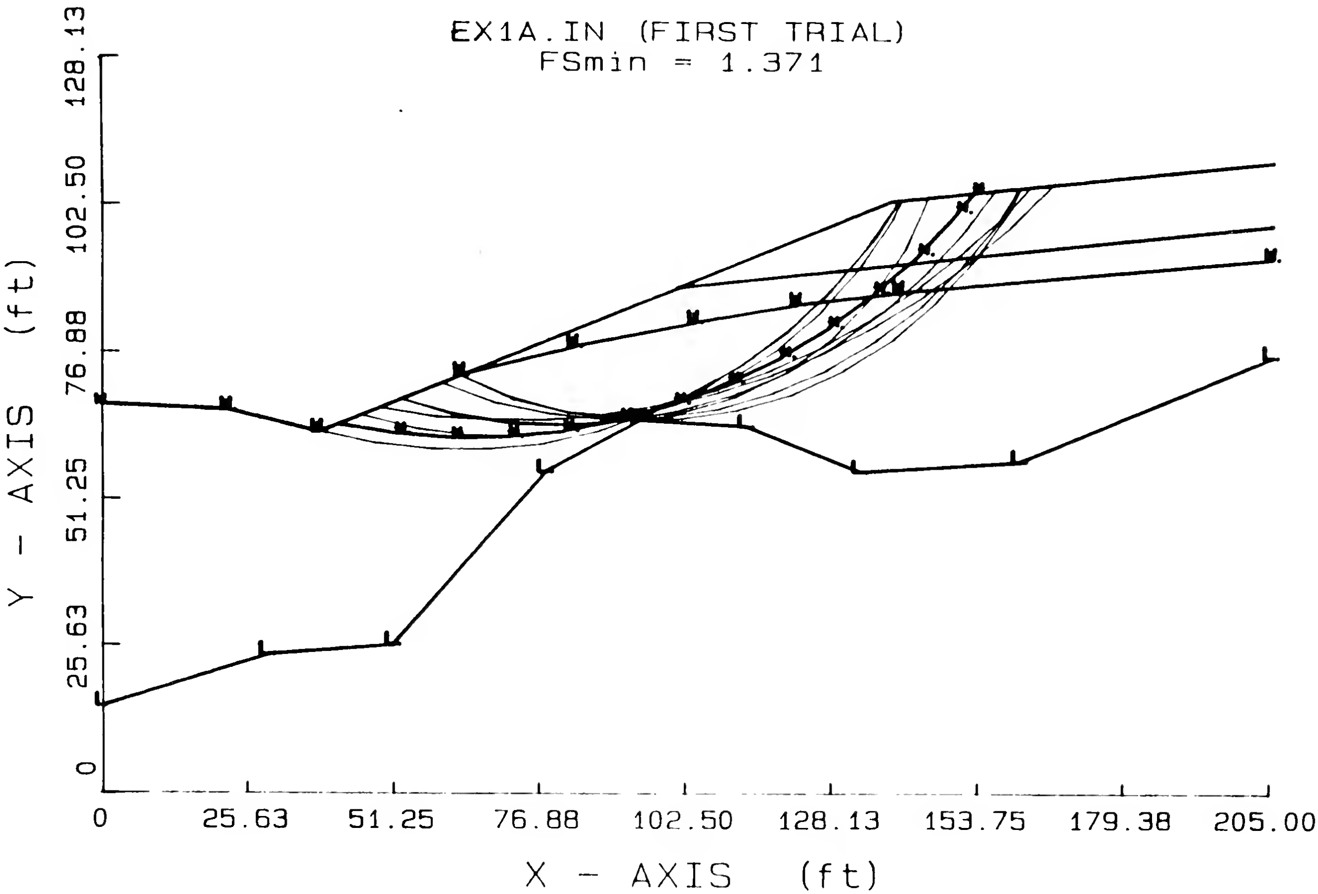


Figure A5: HP-7475A plot with 10 circular surfaces for first trial.

most critical. The most critical surface, giving the minimum factor of safety, is indicated with asterisks on the points defining the surface.

The values of the factors of safety of the ten most critical surfaces range from 1.371 to 1.457 . This is not a large difference, and the chances of locating a circular shaped surface with a factor of safety much less than 1.371 is probably small. The width of the zone occupied by these critical surfaces at the toe and crest indicates that the bedrock influences the stability of the slope by making the value of the factor of safety relatively insensitive to the position of a circular shaped surface. as long as the surface passes near the bedrock surface.

A tendency can be observed that the more critical surfaces of the ten generated occur nearer the toe of the slope. Therefore, there is a good possibility that the critical surface passes through the toe. A second run is made to check this possibility.

Twenty five surfaces are generated from each of 3 initiation points; the leftmost again at the toe, and the rightmost at X= 50 ft. The rightmost initiation point is moved, because critical surfaces were not determined for the right initiation points in the first run. If a circular surface through the toe is critical, then most of the critical surfaces subsequently determined should pass through the toe. The total number of surfaces to be generated, 75, should be adequate because the surfaces generated will be required to satisfy stricter requirements. All surfaces to be generated for the second run will lie in a zone somewhat matching that of the ten most critical surfaces of the first run.

All except one of the critical circular surfaces, determined by the first run, lie behind the crest of the slope, so the left termination limit is moved to the crest at X = 138 ft. Also all the critical surfaces do not extend beyond X = 170 ft, except one, which does so just barely. Therefore, the right termination limit is changed to that position.

Since the minimum angle of inclination of the initial line segments of the critical surfaces is about -24 deg, and no angle exceeded 0 deg, the inclination angle will be restricted between 0 deg and -25 deg.

Because the critical surfaces of the first run all lie at or near the bedrock surface, it would be sufficient to prevent generation of surfaces at shallower depths. This is accomplished by blocking the generation of such surfaces with downward deflecting surface generation boundaries. One boundary is fixed between a point at the ground surface to the right of the last initiation point (63.0, 73.0) and a point a short distance above the bedrock surface (93.0, 67.0). Another is specified between this last point and the crest.

Having modified the requirements each generated surface must satisfy, the second random search was performed using circular surfaces. The next page contains the listing of the raw input for this run.

Following the listing of the raw input data, the output is partially displayed. Since no changes were made to the input data for commands PROFIL, SOIL, and WATER, the output data associated with these commands are omitted. Also, since the output of coordinates for points defining each of the ten most critical surfaces is somewhat bulky, it is omitted. The print character plot (Figure A6) and the HP-7475A plots (Figure A7 & A8) should be sufficient.

The range of values obtained for the ten most critical surfaces is 1.340 to 1.363. The difference is smaller, and all the values are smaller in magnitude than those obtained from the first run. The ten most critical surfaces form a more compact zone than observed in the plots of the first run. Nine of these surfaces pass through the toe of the slope, and all of these are more critical than the one which does not.

There is little justification to refine the search limitations further for another run using circular shape surfaces, so irregular shaped surfaces will be generated and analyzed next.

```
PROFIL
EX1B.IN (Jambu Method-Second Trial-CIRCLE Gen.)
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0. 1
116.4 116.4 0. 0. 0. 0. 1
WATER
1 0.
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
10 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
63. 73. 93. 67.
93. 67. 138. 103.
CIRCLE
1 2
3 25
38. 50. 138. 170.
0. 10. 0. -25.
```

PARTIAL OUTPUT OF SECOND TRIAL

Searching Routine Will Be Limited To An Area Defined By 10 Boundaries
Of Which The First 8 Boundaries Will Deflect Surfaces Upward

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)
1	.00	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00
9	63.00	73.00	93.00	67.00
10	93.00	67.00	138.00	103.00

A Critical Failure Surface Searching Method, Using A Random
Technique For Generating Circular Surfaces, Has Been Specified.

Janbus Empirical Coef. is being used for the case of c & phi both > 0
75 Trial Surfaces Have Been Generated.

25 Surfaces Initiate From Each Of 3 Points Equally Spaced
Along The Ground Surface Between X = 38.00 ft.
and X = 50.00 ft.

Each Surface Terminates Between X = 138.00 ft.
and X = 170.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y = .00 ft.

10.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -25.0
And .0 deg.

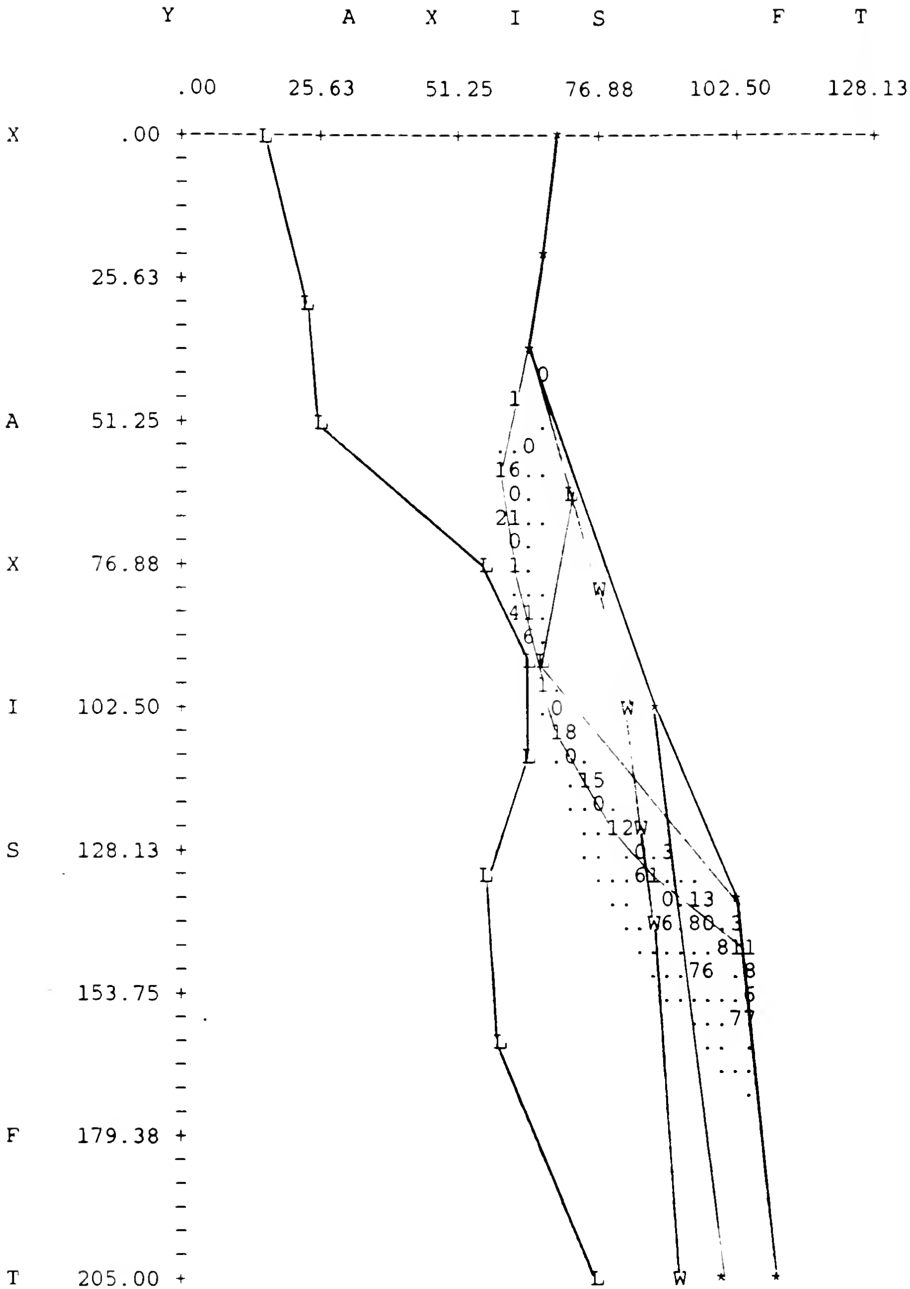


Figure A6: Print character plot for second trial

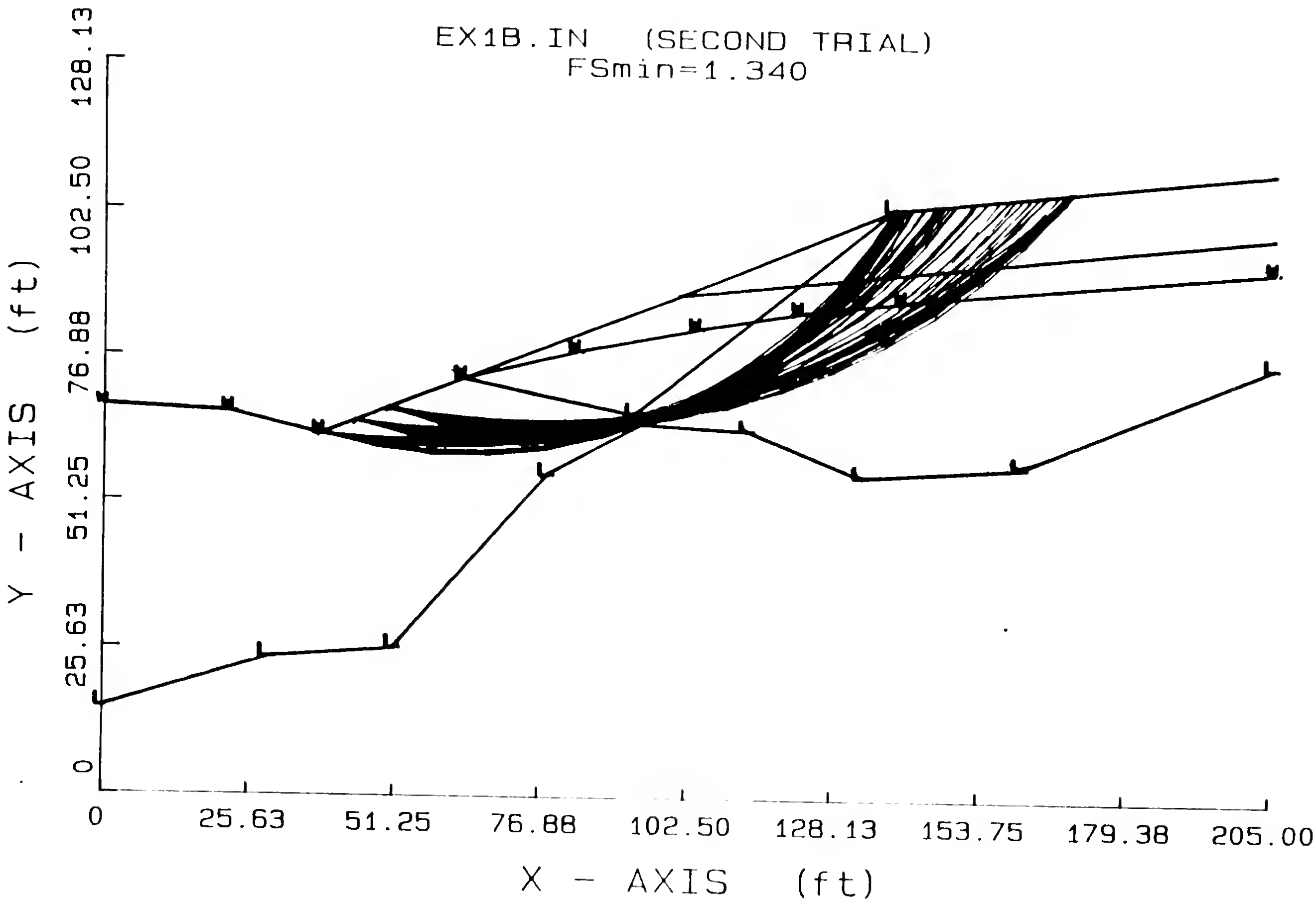
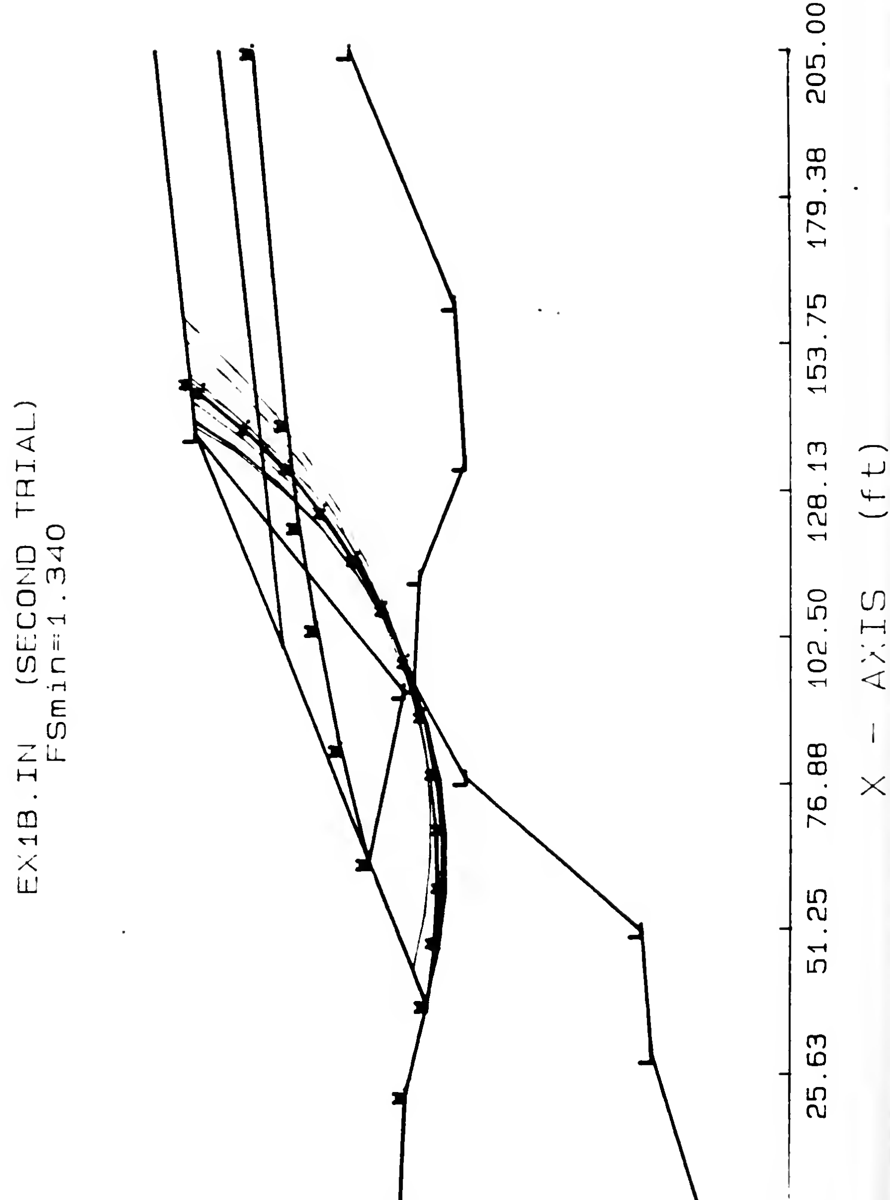


Figure A7: HP-7475A plot with 100 circular surfaces for second trial.


EX1B.IN (SECOND TRIAL)
FSmin=1.340
X - AXIS (ft)
Y - AXIS (ft)
0
25.63
51.25
76.88
102.50
128.13
153.75
179.38
205.00
0
25.63
51.25
76.88
102.50
128.13

(b) USE OF RANDOM TYPE GENERATOR

Using information obtained from analyzing circular surfaces, it is assumed that the critical irregular surface will pass through the toe, and that it will lie near or at the bedrock surface. From the toe of the slope 30 irregular shaped surfaces are randomly generated. Only 30 surfaces may seem inadequate, but it is more than was generated from the toe of the slope for the second run.

All the critical circular surfaces of the second run terminate to the left of the point X = 160 ft, so the right termination limit is moved to that position. The length of the line segments to define the irregular surfaces is specified as 15 ft. The angle of inclination of the initial line segment is restricted between -15 deg and -45 deg. Although the circular search indicated shallower angles of inclination for the critical surface, it is thought that the initial inclination is controlled by the circular shape of the surfaces generated, and if the surfaces were not restricted to this shape, the angle of inclination of the initial line segment of the critical surface could be steeper.

The listing of the raw input data and a portion of the output for the third run follow on the next pages. The range in values of the factor of safety for the ten most critical irregular surfaces is 1.347 to 1.397 the most critical being somewhat higher than that of the second trial.

Viewing the HP plot of the ten most critical irregular surfaces (Figure A9),it can be observed that these surfaces have steeper angles at inclination for the initial line segments. The initial line segment of the most critical irregular surface is inclined at about 38.5 deg. Note the fairly compact zone. Tightening the surface generation requirements would be of little benefit for another run using the irregular surface generator. An application of the sliding block generator would be better.

```
PROFIL
EX1C.IN (Jambu Method-Third Trial-Random Gen.)
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0. 1
116.4 116.4 0. 0. 0. 0. 1
WATER
1 0.
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
10 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
40.5 64. 93. 68.
93. 68. 138. 103.
RANDOM
1 2
1 30
38. 38. 138. 160.
0. 15. -15. -45.
```

Searching Routine Will Be Limited To An Area Defined By 10 Boundaries
Of Which The First 8 Boundaries Will Deflect Surfaces Upward

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)
1	.00	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00
9	40.50	64.00	93.00	68.00
10	93.00	68.00	138.00	103.00

A Critical Failure Surface Searching Method, Using A Random Technique For Generating Irregular Surfaces, Has Been Specified.

Janbus Empirical Coef. is being used for the case of c & phi both > 0
30 Trial Surfaces Have Been Generated.

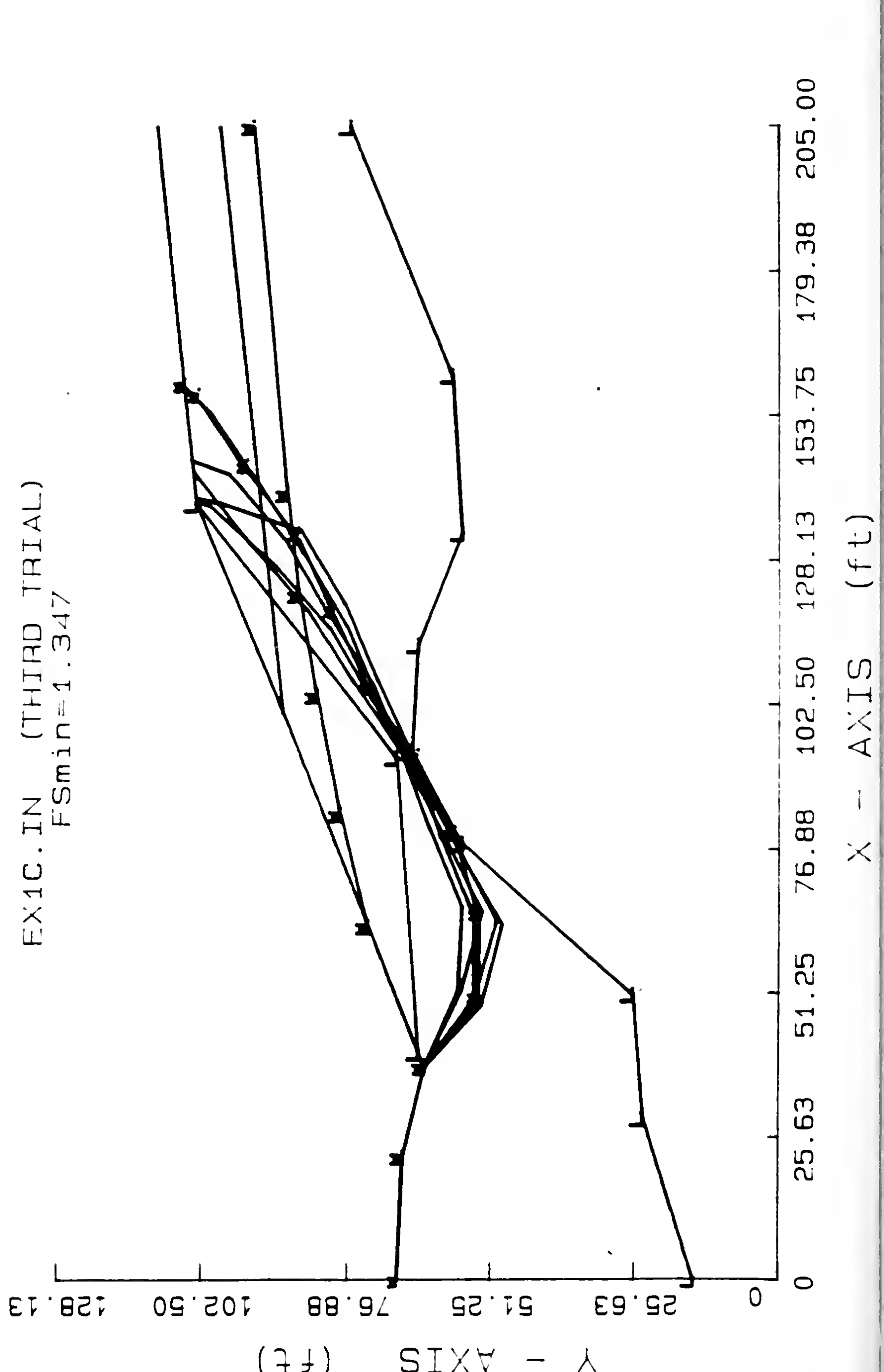
30 Surfaces Initiate From Each Of 1 Points Equally Spaced
Along The Ground Surface Between X = 38.00 ft.
and X = 38.00 ft.

Each Surface Terminates Between X = 138.00 ft.
and X = 160.00 ft.

Unless Further Limitations Were Imposed, The Minimum Elevation
At Which A Surface Extends Is Y = .00 ft.

15.00 ft. Line Segments Define Each Trial Failure Surface.

Restrictions Have Been Imposed Upon The Angle Of Initiation.
The Angle Has Been Restricted Between The Angles Of -45.0
And -15.0 deg.


EX1C.IN (THIRD TRIAL)
FSmin=1.347
X - AXIS (ft)
Y - AXIS (ft)
0
25.63
51.25
76.88
102.50
128.13
153.75
179.38
205.00

(c) BLOCK TYPE GENERATOR.

The position of the most critical surface of the third run is used as a probable location of the most critical surface. Nine degenerate boxes are specified along the path of this surface. They are specified from left to right in a manner so they do not overlap.

The first box on the left is specified as a point at the toe of the slope. The next three boxes are specified as vertical lines, 4 feet long, straddling the critical irregular surface. The fifth box is also specified as a vertical line, but its length is specified as only 2 feet. Due to the proximity of the bedrock surface, it is positioned just above the bedrock. The sixth box is specified as a point just above the bedrock surface at the high point. The next two points are again specified as 4 foot vertical line segments, straddling the critical surface. The final box is specified as a horizontal line segment 5 feet in length, again straddling the critical irregular surface.

Points are randomly picked from within each box in sequence and connected to form part of a surface. To complete the active portion of a surface, 20 ft line segments are specified. Fifty surfaces are generated.

The listing of the raw input data and a portion of the generated output follow on the next pages. The values of the factor of safety ranged from 1.288 to 1.303 for the ten most critical surfaces, and the ten most critical surfaces form a very tight zone. Note the relative position of these surfaces with respect to the boxes, which can be seen in Figure A10. Another run would not be justified.

```
PROFIL
EX1D.IN (Jambu Method-Fourth Trial-BLOCK Gen.)
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0. 1
116.4 116.4 0. 0. 0. 0. 1
WATER
1 0.
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
8 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
BLOCK
1 2
50 9 20.
38. 63. 38. 63. 0.
48. 55. 48. 55. 4.
58. 52. 58. 52. 4.
68. 53. 68. 53. 4.
78. 57.01 78. 57.01 2.
94. 65.01 94. 65.01 0.
120. 75. 120. 75. 4.
130. 82. 130. 82. 4.
135. 92. 140. 92. 0.
```

PARTIAL OUTPUT FOR FOURTH TRIAL

Searching Routine Will Be Limited To An Area Defined By 8 Boundaries Of Which The First 8 Boundaries Will Deflect Surfaces Upward

Boundary No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)
1	.00	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00

Janbus Empirical Coef is being used for the case of c & phi both > 0

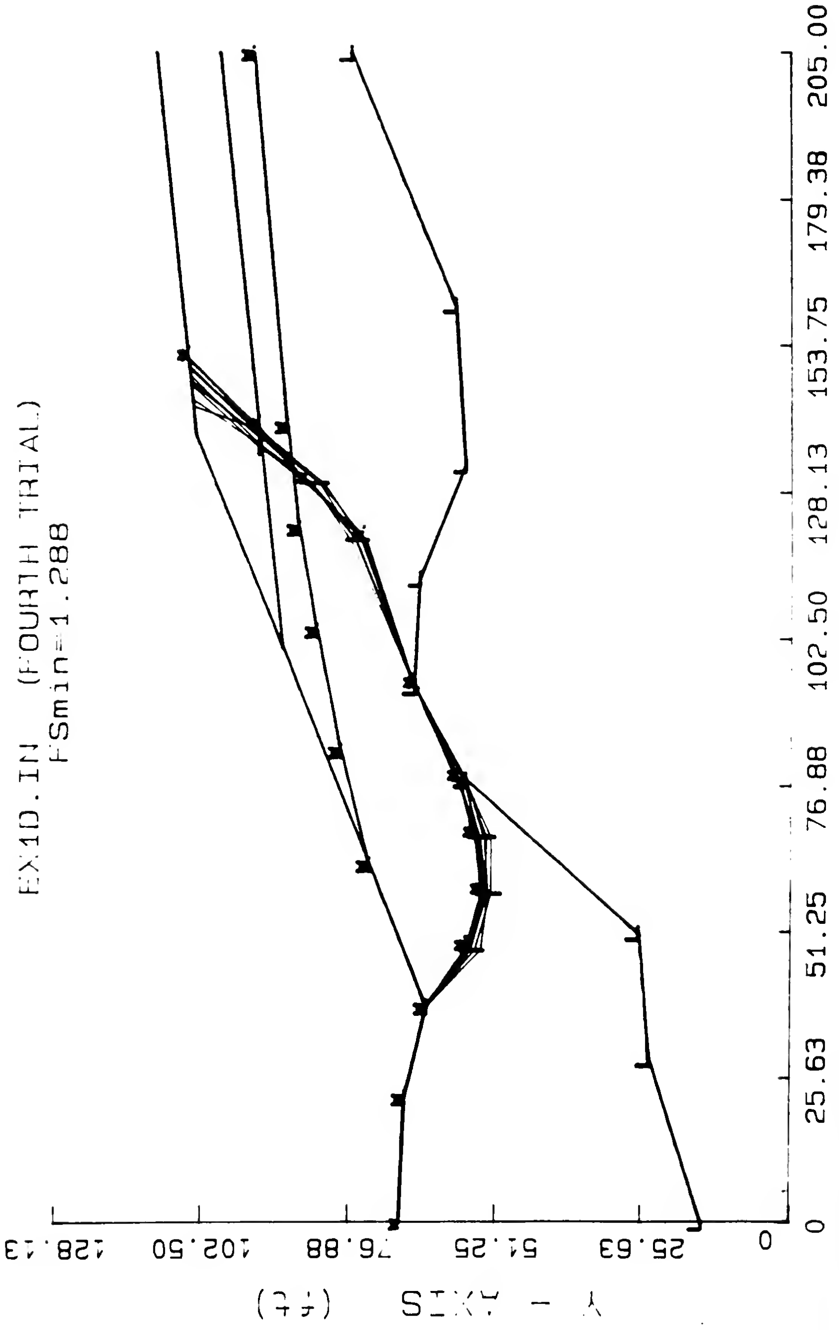
A Critical Failure Surface Searching Method, Using A Random Technique For Generating Sliding Block Surfaces, Has Been Specified.

50 Trial Surfaces Have Been Generated.

9 Boxes Specified For Generation Of Central Block Base

Length Of Line Segments For Active And Passive Portions Of Sliding Block Is 20.0

Box No.	X-Left (ft)	Y-Left (ft)	X-Right (ft)	Y-Right (ft)	Height (ft)
1	38.00	63.00	38.00	63.00	.00
2	48.00	55.00	48.00	55.00	4.00
3	58.00	52.00	58.00	52.00	4.00
4	68.00	53.00	68.00	53.00	4.00
5	78.00	57.01	78.00	57.01	2.00
6	94.00	65.01	94.00	65.01	.00
7	120.00	75.00	120.00	75.00	4.00
8	130.00	82.00	130.00	82.00	4.00
9	135.00	92.00	140.00	92.00	.00


EX1D.IN (FOURTH TRIAL)
FSmin=1.288
0
25.63
51.25
76.88
102.50
128.13
153.75
179.38
205.00
X - AXIS (ft)
0
25.63
51.25
76.88
102.50
128.13
Y - AXIS (ft)

C. COMPARISONS OF RESULTS - CONCLUSIONS.

The same example was ran using Bishop and Spencer methods of analysis. Table A1 gives the safety factors of the above problem using different generators, and methods.

TABLE A1

	CIRCULAR	RANDOM	BLOCK
JANBU	1.340	1.347	1.288
BISHOP	1.375		/
SPENCER	1.380	1.502	1.420
% Diff. between Janbu-Spencer	-2.9	-10.32	-9.30

Note: Bishop method is applicable only for circular surfaces.

The simplified Janbu method of slices, normally applied in the STABL program, gives somewhat conservative results (FS=1.340) compared to Spencer method (FS=1.380), whereas the modified Bishop method (FS=1.375) gives results very close to those obtained by Spencer method. Further, the conservatism of the Janbu method (compared to Spencer method) seems to be larger for irregular (-10.32%) and sliding block type failure surfaces (-9.30%) than for failure surfaces of circular shape (-2.90%).

The results obtained tend to confirm the conclusions of Eva Boutrup (1977,pp. 170-202) for the same program. However in the same report Chapter VI, Section

6.4 it was found that STABL with the Janbu method may give non conservative and erroneous results for failure surfaces that intersect the top of the slope at steep angles, and where the strength of the soil is defined mainly in terms of strength intercept c (c').Since this problem arose mainly for deep circular failure surfaces, it was solved by including in the STABL program the modified Bishop solution, applicable to circular failure surfaces. It is recommended that the BISHOP METHOD BE USED FOR CIRCULAR FAILURE SURFACES IN GENERAL (use CIRCL2 instead of CIRCLE).

Precautions should be taken if a similar situation occurs for irregular shaped failure surfaces. In any case it is advisable to make a preliminary estimate of the factor of safety by means of simple slope stability charts for homogeneous slopes (averaging soil parameters, etc.).

An example problem utilizing the option of defining more than one piezometric surface is presented by Eva Boutrup (1977, Section 4.4). Section 4.5 gives some additional advice in the use of STABL.

APPENDIX B

MISCELLANEOUS INFORMATION ON STABL

A. Development of STABL

The 2-D computer program STABL was developed at a time when most highway agencies analyzed slope stability using two common techniques:
(a) computer-aided, grid-type circular searches, and
(b) block analyzes for simple and specified surfaces.
Circles were often assumed to be the appropriate shape for potential failure surfaces simply because there was no other shape which could be used for computerized searching.

In the last two decades, improvements in 2-D slope stability analysis have proceeded in several directions; one of these is contained in STABL, in the form of computerized searching with non-circular shapes. The non-circular routines RANDOM and BLOCK were first reported by Siegel (1975a) as well as a random (as opposed to a grid) type search with circles (CIRCL2). Favorable comparisons of the FOS values generated by STABL with those for the same surfaces by other methods of slices were reported by Boutrup (1977).

STABL was placed on line for routine use in 1976 by the Indiana Department of Highways (IDOH), and after being reported in the open literature (References 13, 2, 3, 4, 14), the program began to be adopted by many agencies. STABL has been modified in many ways over the past twelve years, and users of the program have helped greatly in debugging operations. The present version of STABL is called PCSTABL5M (written for micro-computers). It retains all the capabilities and options of the original one. In addition, it includes provision for the analysis of tied-back slopes, and the Spencer's method of slices.

B. Assumptions

STABL assumes that the instability to be prevented would be two-dimensional. In reality, all sliding failures must be 3-D, with the end/edge resistance furnishing additional safety against instability . For more quantitative information on the comparison of FOS_{3D} to FOS_{2D}, see Chen (1981) and Lovell (1982) . In general, $FOS_{3D} > FOS_{2D}$, but the difference may be small, and in certain special cases $FOS_{2D} > FOS_{3D}$. Where the stability problem is perceived to be definitely 3-D, the engineer is encouraged to use BLOCK3 or LEMIX codes of Chen (1981).

STABL uses simplified methods of slices for determination of FOS. The alternative requires solutions with extensive iteration and the consequent problems of nonconvergence in these iterations. Boutrup (1977) has shown that the simplified methods after Janbu and Bishop give reasonably precise values of FOS.

Agencies staffed with appropriate mathematical and software skills can insert any desired slices solution into the program... simplified or total equilibrium. STABL is a stability analysis system, of which the method of slices detail, is a small part.

The selection of a center of moments for the slices analysis is an intriguing point. In the simplified approaches, the free body is not iterated into equilibrium, and accordingly, the FOS value is peculiar to the center selected. This is true even for the circle, where the circle center is arbitrarily selected in the simplified Bishop method. For other shapes, there is usually no "center" to select for moments. After much study of this question (Carter, 1971; Siegel, 1975a, Boutrup, 1977), the circle center is used for CIRCL2, and a very long moment arm is used for BLOCK, BLOCK2, and RANDOM. The latter choice means that these noncircular surfaces are analyzed with the same slice assumptions as the simplified Janbu method.

STABL values may be checked for a specific failure surface in several ways. CIRCL2 should yield about the same FOS (for the same circle) as any other computerized analysis for circles. To determine that this is indeed the case, the new user of STABL can run CIRCL2 in parallel with his present method. BLOCK or BLOCK2 can be checked approximately (for a specific block) either manually or perhaps by existing charts. RANDOM is amenable to approximate manual checks.

C. Modifications and revisions of STABL

Since STABL was developed by Ronald A. Siegel in 1975 it has undergone much modification and revision. The first major improvement of the program was done by Eva Bountrup in 1977. The new program, STABL2 introduced new features in STABL such as:

a. In addition to the three original surface generators, which were the circular arc, the irregular, and the sliding block type surface, a new sliding block surface was introduced, which generates the active and passive portions of the surface according to Rankine theory.

b. The water surface option was extended, so that it was possible to define different piezometric surfaces for different layers.

c. The modified Bishop factor of safety was introduced for circular failure surfaces, in addition to the simplified Janbu method.

However due to a much more extensive use of STABL for teaching purposes, and also as a request of users, STABL was modified once again by J. R. Carpenter in 1983-86. Carpenter modified STABL to handle tieback loading (Carpenter; 1986). The new program was called STABL4. Also he introduced the Spencer method of analysis in STABL5. (Carpenter; 1985).

A latest modification of STABL was accomplished recently by J. E. Thomaz, and J. R. Verduin (Verduin; 1987). This modification included the introduction

of the Janbu coefficient, and pore pressure modifications.

D. Units

All units used for any one problem must be consistent. The printed output is limited to the following units for dimensioning.

Length	(FT)
Unit Weight	(PCF)
Stress	(PSF)
Direction	(DEG)

Metric units or any set of consistent units can be used. It must be kept in mind, however, that the printed output will bear the units listed above. A consistent set of metric units for example would be:

Length	(M)
Unit Weight	(KG/M**3)
Stress	(KG/M**2)
Direction	(DEG)

E. Problem Size Limitations.

STABL as dimensioned in the program listing is capable of handling problems defined as below.

Data	*Maximum Number*
profile boundaries (total)	100
piezometric surfaces (total)	10
points defining a single water surface	40
points defining a specified trial failure surface	100
surface generation boundaries	20
uniformly distributed surcharge boundary loads	10
soil types (total)	20
anisotropic soil types	10
tieback loads	10
direction ranges of each anisotropic soil type	10
boxes for sliding block surfaces	10

*The program can be adjusted to handle larger problems by changing dimension statements. The availability of the computing machine's memory core will take precedence with regard to how large a problem can be ultimately handled.

COVER DESIGN BY ALDO GIORGINI